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LOW-COST JET FUEL STARTER DESIGN STUDY

A. Gabrys, et al

Teledyne CAE

Prepared for:

Air Force Aero Propulsion Laboratory

2 December 1974

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the preliminary design and cost analysis of a low cost jet fuel starter. This unit is an accessory to be used for starting main aircraft propulsion units, and requires only jet fuel and battery power to achieve safe reliable starts. The basic starter has a peak output of 150 horsepower, is 10.0 inches in diameter, 20 inches long and weighs 98 pounds. The starter is capable of operating over an ambient temperature range of −65°F to 130°F and at altitudes up to 8,000 feet. The design features a radial air inlet, axial exhaust, and a low speed concentric shaft, with front power output. The low speed (low stress) permits simple construction and low cost fabrication techniques with an overall reduction in total parts and cost when compared with typical high speed units. The cost analysis indicates that the starter selling price is less than $8,000 per unit in quantities of 100 per year, including tooling and R & D costs amortized over 2500 units.

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FOREWORD

This is the final Technical Report prepared by Teledyne CAE. The effort was sponsored by the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio under Contract No. F33615-74-C-2041 for the period 1 May 1974 to 2 December 1974. The work herein was accomplished under Project 3145, Task 01, Work Unit Number 12, with Lt. John G. Grelck III, AFAPL/POP-1, as Project Engineer. Mr. A. Gabrys and R. Smith of Teledyne CAE were technically responsible for the work.

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SECTION

INTRODUCTION

The purpose of this study was to define a low cost jet fuel starter with a selling price of less than $8,000. The jet fuel starter is an accessory used to start aircraft propulsion units. It is permanently mounted either directly on the main engine, or on a remote gearbox. The starter must be compact to fit within the limited space available on modern aircraft, and sufficiently lightweight to be carried on board without seriously degrading the overall aircraft performance. The use of jet fuel for the starter eliminates the problem of starting time and logistics resulting from using other fuels such as cartridges or external power such as compressed air starter carts.

Current jet fuel starter designs are small, scaled-down versions of larger free-turbine engines utilizing conventional primary propulsin gas turbine precision techniques in their execution. The net result is a unit cost in the $15,000 to $20,000 range. To achieve the desired cost reduction of approximately 50 percent, new and innovative design techniques must be employed to reduce the expensive complexity and precision associated with conventional long life gas turbine design. The starter design objective of 2000 starts at 45 seconds per start results in only 25 hours of operation, and therefore permits a different design approach. The small amount of fuel used per start, less than 1 and 1/2 quarts, totally eliminates one major requirement of conventional engines; that of low fuel consumption. The starter design approach therefore must concentrate on safety, reliability, durability and low cost.

The starter design must also satisfy real-life military fiscal requirements, such as low procurement lots. For this study, a production rate of 100 per year has been used, with tooling and R & D amortized over 2500 units.

The starter is required to operate only as a starter, and continual discipline must be exercised to assure that desirable but unnecessary features are not added to drive the cost up without enhancing the ability to perform safe, reliable starts.

SECTION II

ENGINE DESIGN

ENGINE ARRANGEMENT

The Teledyne CAE JFS206 jet fuel starter is a compact turbine engine for starting main propulsion units. The engine (Figure 1) is composed of a gas generator, a power turbine, a reduction gear assembly, an accessory drive and a control and starting system. The gas generator consists of an axial flow compressor, an annular combustor, an axial flow turbine, a housing, and support structures. The annular reverse-flow combustor overlaps the axial compressor to provide a compact engine 10 inches in diameter, 20 inches long, and weighing only 98 pounds.

The gas generator rotor is straddle mounted, with a thrust bearing in the front, and a roller bearing in the rear. The rotor operates at 43,500 rpm which is only 70 percent of the speed normally used in high performance engines in this power class. Stress levels are thus only 50 percent of those encountered in higher speed engines. Low rotor stress levels allow the use of a large bore compressor rotor that accommodates a simple through-shaft design and also allows the use of die cast aluminum compressor rotors, each contributing to achievement of the cost objective.

The power turbine module is an investment cast rotor and a through-shaft to the cold end of the engine. The through-shaft design requires only two bearings for the rotor; shaft and pinion gear support from the thrust bearing at the front, and a roller bearing at the rear. The through-shaft design eliminates the complex costly exhaust collector required for a rear power-takeoff engine and locates the reduction gears in a cool environment.

The reduction gears are forward of the air inlet in a compartment with the rotor shaft thrust bearings. The low rotor speed of 29,000 rpm allows for a two-stage reduction to provide the necessary output speed of approximately 3,000 rpm for a normal start, and 3,300 to 3,500 rpm for starter cutout. An overrunning clutch is provided on the power output shaft to disengage the engine from the main propulsion engine. Reduction gears, reduction gear bearings, rotor thrust bearings and the accessory drive are "pot" lubricated within the compartment, eliminating the need for a circulatory system and the attendant components.

The accessory drive provides the gas generator power input to the fuel control system and transfers the electric starter drive power to the jet fuel starter. The spur and face gears provide a simple drive train with an overrunning clutch that disengages the electric starter from the gas generator. The same drive train provides the mechanical drive to the centrifugal boost pump of the fuel control system.

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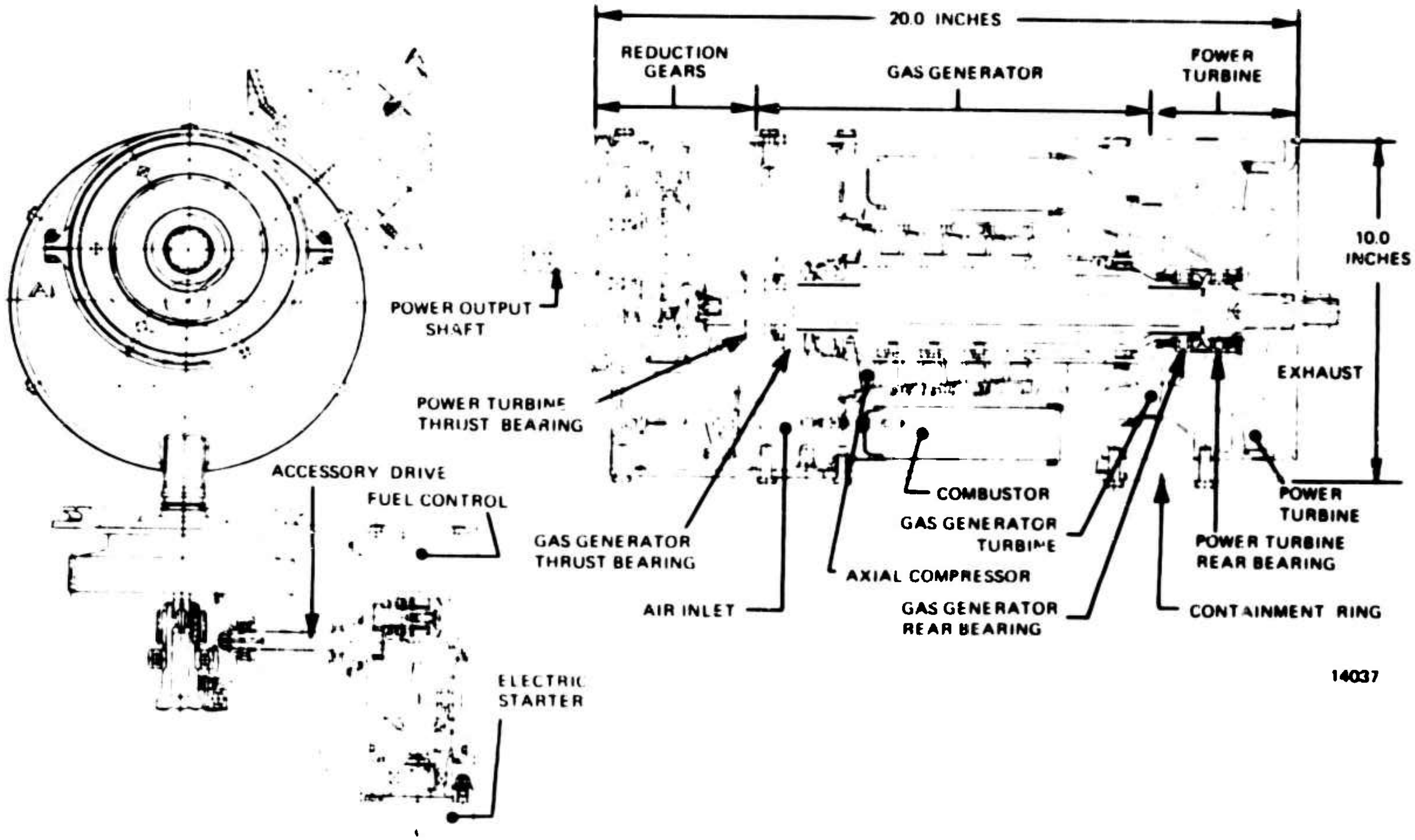

Figure 1. Teledyne CAE JFS206 Jet Fuel Starter

The basic configuration of the jet fuel starter uses low rotor speeds which allow for simplified lubrication systems. The bearings and gears are located in the pot lubricated front end with the exception of the rotor roller bearings which are lubricated by a waste fuel system. This combination lubrication system has been successfully demonstrated on the Teledyne CAE J402-CA-400 HARPOON engine and the Teledyne CAE Model 373-2, Variable Speed Training Target engine (VSTT).

ENGINE PERFORMANCE

Sea level static design point engine performance is presented in Figure 2. A low performance cycle was chosen because specific fuel consumption is not an important criterion, because a very small amount (less than 1.5 quarts) of fuel is consumed per start.

Component efficiencies and pressure losses have been degraded relative to conventional gas turbine practice, thereby eliminating expensive development programs. At design point for sea level static flight conditions, engine inlet total pressure recovery is 99 percent.

The four-stage axial compressor, with a pressure ratio of 2.86, was developed in prototype through Teledyne CAE in-house funding. The compressor map measured during rig testing is shown in Figure 3. The JFS cycle compressor efficiency has been degraded to 80 percent from that shown on the test map. At sea level static design point, the compressor airflow is 2.23 lbs/sec at 43,500 rpm.

The gas generator turbine inlet temperature is 1800°F, with an adiabatic efficiency of 82.5 percent. The free turbine is designed to operate at 29,000 rpm, with an efficiency of 80 percent at sea level static condition. Total pressure loss is 1.5 percent in the inter-turbine passage and 5 percent in the combustor.

The exhaust nozzle operates at a 1.01 pressure ratio with a 5 percent exhaust total pressure loss at the design point.

The estimated starter torque and horsepower characteristics, as a function of output shaft speed, are shown in Figure 4.

Based on these component efficiencies and internal pressure losses, the jet fuel starter will deliver 150 horsepower at 1.3 lbs/hr-bhp BSFC, at sea level static design condition.

The degraded performance levels allow relatively large running clearances between the rotating and static structures. Since the static structures heat and cool more rapidly than the heavier rotating members, the rotors will retain their increased dimensions after shutdown. The engine performance for consecutive starts should show improvement in the form of higher starting torques for successive starts because of the reduced running clearances present until the temperature is stabilized.

OVERALL PERFORMANCE:	
POWER TURBINE OUTPUT - HP.	150
BSFC - LBS/HR -BHP	1.30
AIRFLOW - LBS/SEC.	2.23
INLET CONDITIONS:	
AMBIENT TEMPERATURE - °F	58.7
AMBIENT PRESSURE - psia	14.7
INLET PRESSURE RECOVERY - %	99.0
COMPRESSOR:	
PRESSURE RATIO	2.86:1
ADIABATIC EFFICIENCY - %	80.0
GAS GENERATOR TURBINE:	
TURBINE INLET TEMPERATURE	1800
ADIABATIC EFFICIENCY - %	82.5
POWER TURBINE:	
ADIABATIC EFFICIENCY - %	80.0
MECHANICAL EFFICIENCY - %	96.0
TOTAL PRESSURE LOSS - %	
COMBUSTOR	5.0
INNER TURBINE PASSAGE	1.5
EXHAUST DIFFUSER	5.0
SPEED - RPM	
GAS GENERATOR	43,500
POWER TURBINE	29,000

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Figure 2. Sea Level Static Design Point Engine Performance

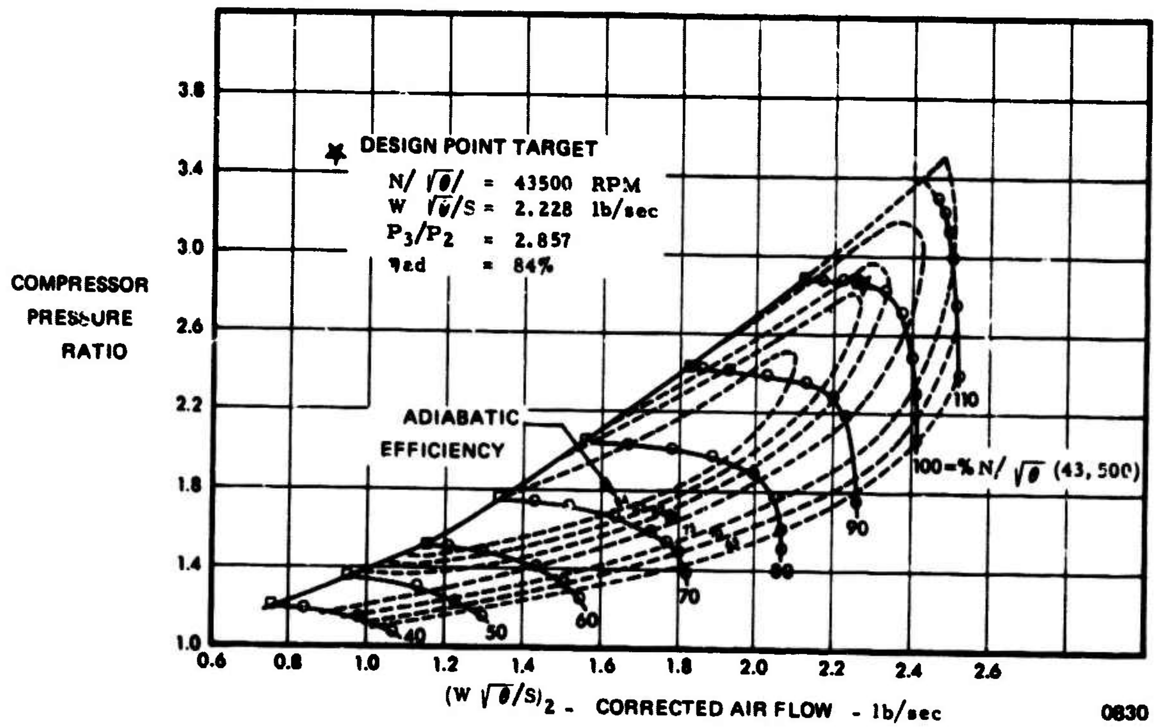

Figure 3. Compressor Performance Map Developed From Rig Testing

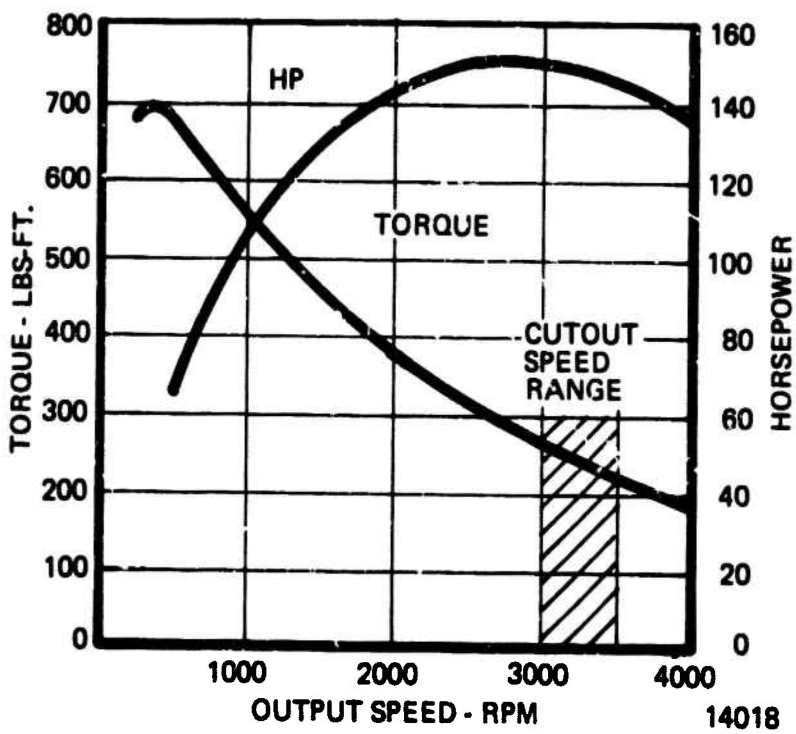

Figure 4. JFS206 Starter Torque and Horsepower Characteristics.

The necessary time between start attempts is based on the nature of the preceeding attempt. If the preceeding start was successfully completed through shutdown, the succeeding start may be initiated with no time limitations. Engine bow, the curvature caused by the temperature difference between the top and bottom of the starter, does not begin to have an effect until after 60 seconds from shutdown. The jet fuel starter with its small diameter and short bearing span will experience a temperature differential under 30°F and a length differential of less than 0.004 inch at the outer casting. The resultant bow reduces the radial clearance less than 0.002 inch, which is minute compared to normal running clearances.

The number of starts is dependent upon the electric starter of the JFS206. Heat generation and build-up within the electric starter motor can be affected by a number of factors. With proper voltage and amperage to the electric starter, it is anticipated that ten consecutive start cycles may be run on the JFS206. With a ten minute respite, five more consecutive start cycles may be run before this process may be repeated two more times for a total of twenty-five starts within a one hour period.

In the event the main engine does not achieve a successful start and has sufficient drag to keep the starter from reaching its cut-out speed, the jet fuel starter may be operated for a two minute interval. After this interval, the start must be manually aborted to permit the lubricating oil in the sump to cool for a period of five minutes. Two more starts may be attempted for the two minute interval with the intervening five minute cooling period before the engine must be allowed to cool for sixty minutes.

In the event of an unsuccessful ignition of the jet fuel starter, the electric starter motor can be operated continuously up to two minutes. A ten minute shutdown is then required before operating continuously for another sixty second interval. Repetition of the ten minute shutdown and sixty seconds of operation may be continued for the duration of the electric power supply. If the electric starter motor has been running less than the two minute interval and the pilot has aborted the start (manual switch), a second attempt to start may be made after a 30 second interval, allowing the raw fuel to drain from the combustor section of the JFS206 starter.

The large running clearances between the rotating and static structures precludes wear between these surfaces. The degradation of performance is therefore primarily due to the erosion of the hot end components after a period of operation. The low turbine inlet temperature of 1800°F and previous starter engine experience indicates that the degradation of performance can be anticipated to be less than 5 percent of the torque over the 2000 start life.

ROTATING STRUCTURE

The JFS206 engine consists of two main rotating structures, the gas generator rotor and the power turbine rotor assembly.

The gas generator rotor (Figure 5), consists of a simple Greek Ascoloy shaft, a cast IN-100 turbine rotor, a Greek Ascoloy spacer, die cast aluminum compressor rotors, Greek Ascoloy pins, and a silver plated locking nut (to prevent galling). The remaining steel components are corrosion resistant and do not require special coatings or platings.

The compressor rotor stages are centered, and transmit their torque by means of radial pins. With the exception of the first stage rotor, they are retained by an overlap extension of the adjacent rotor. The first stage rotor is similarly pinned, but the pins are radially retained by a separate ring. This ring is axially retained by tangs bent into place from a sheet metal ring positioned by the pins. Three radial pins are used per stage. The radial pin holes through the rotors and shaft are machined at assembly, thereby eliminating the requirement for precision spacing between the pin holes. The use of the radial pins for centering the rotors eliminates the requirement for precision piloting between rotors and shaft and provides good centering under all conditions of elastic and thermal growths. The turbine rotor is piloted on the shaft from the rear and held in place with a large diameter nut which incorporates a positive locking ring. This feature provides disassembly from the rear of the starter for maintainability and replacement of the hot-end components.

The four compressor rotors are identical die castings to minimize tooling costs and take full advantage of high volume die casting. The tips are then machined to the required height for each stage to provide flow path control.

The low gas generator rotor speed of 43,500 rpm for this size rotor results in stress levels of approximately 50 percent of those found in conventional high performance rotors. This permits the use of automotive type die cast axial compressor stages for low cost, while retaining adequate structural margins. Only the first stage axial compressor rotor was stress analyzed because succeeding stages will have lower stress levels due to the shorter blade height. The SC84A aluminum die casting material has a minimum allowable yield strength of 19,500 psi. The blade stress at 43,500 rpm is only 6,820 psi maximum with predicted failure at a speed of 73,700 rpm, providing a speed margin of safety of 1.69. The rotor has an average tangential stress of 10,060 psi at 43,500 rpm and has a predicted burst speed of 60,660 rpm, providing a margin of safety of 1.39.

The cast IN-100 gas generator turbine rotor was similarly analyzed. The IN-100 material at temperature has an ultimate strength of 110,000 psi and a yield strength of 95,000 psi. The tangential and radial stresses throughout the rotor are plotted on Figure 6 for the 43,500 rpm rotor speed. The rotor has a predicted burst speed of 65,600 rpm, providing a margin of safety of 1.51.

The gas generator rotor shaft of Greek Ascoloy can have a relatively large diameter due to the low rotor stresses predicted. The shaft was subjected to critical speed analysis using varying bearing support stiffnesses (Figure 7). Selection of the bearing support stiffnesses is indicated on the graph to provide a first critical at 38 percent under the operating speed and a second critical at 29 percent over the operating speed.

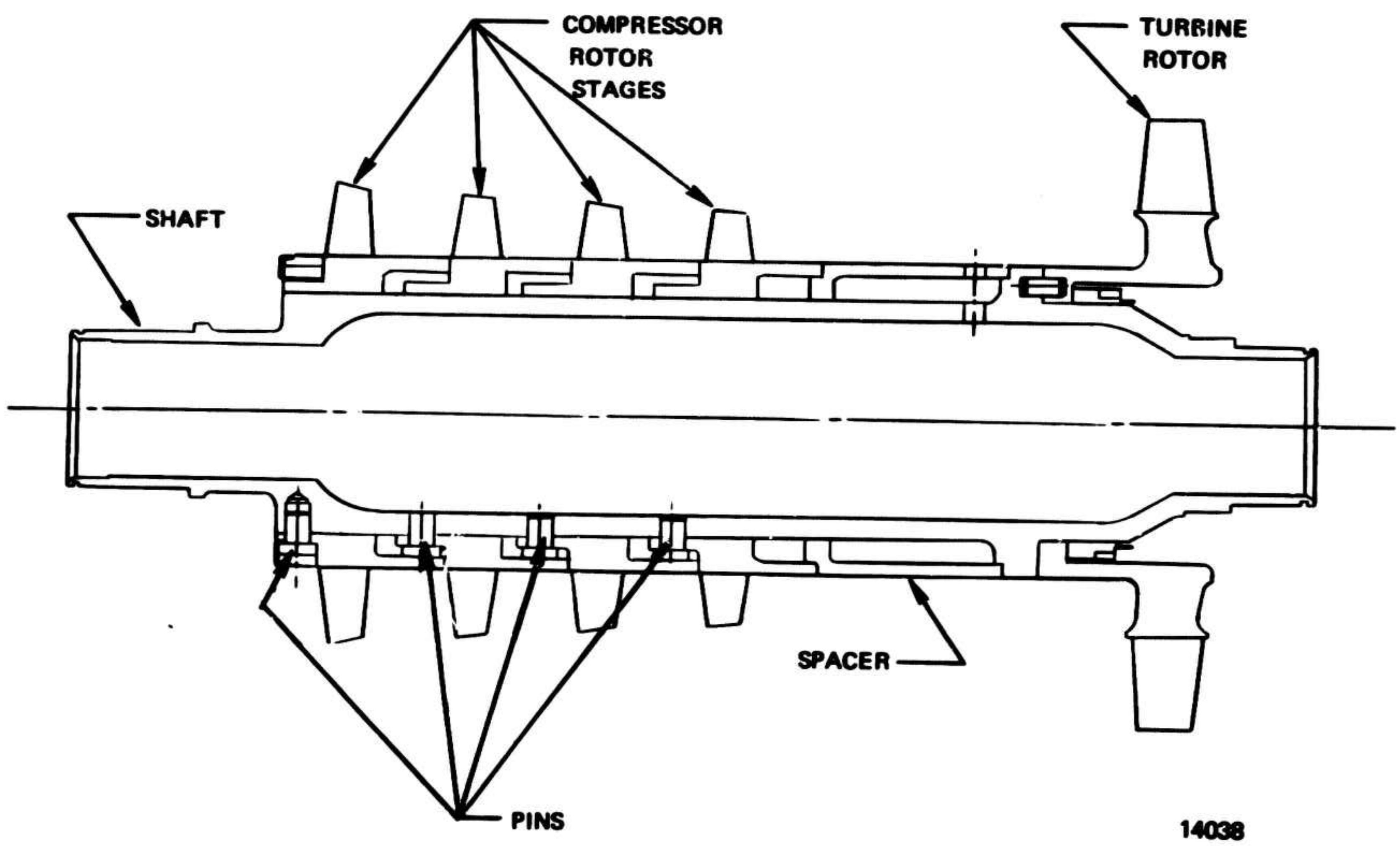

Figure 5. Gas Generator Rotor

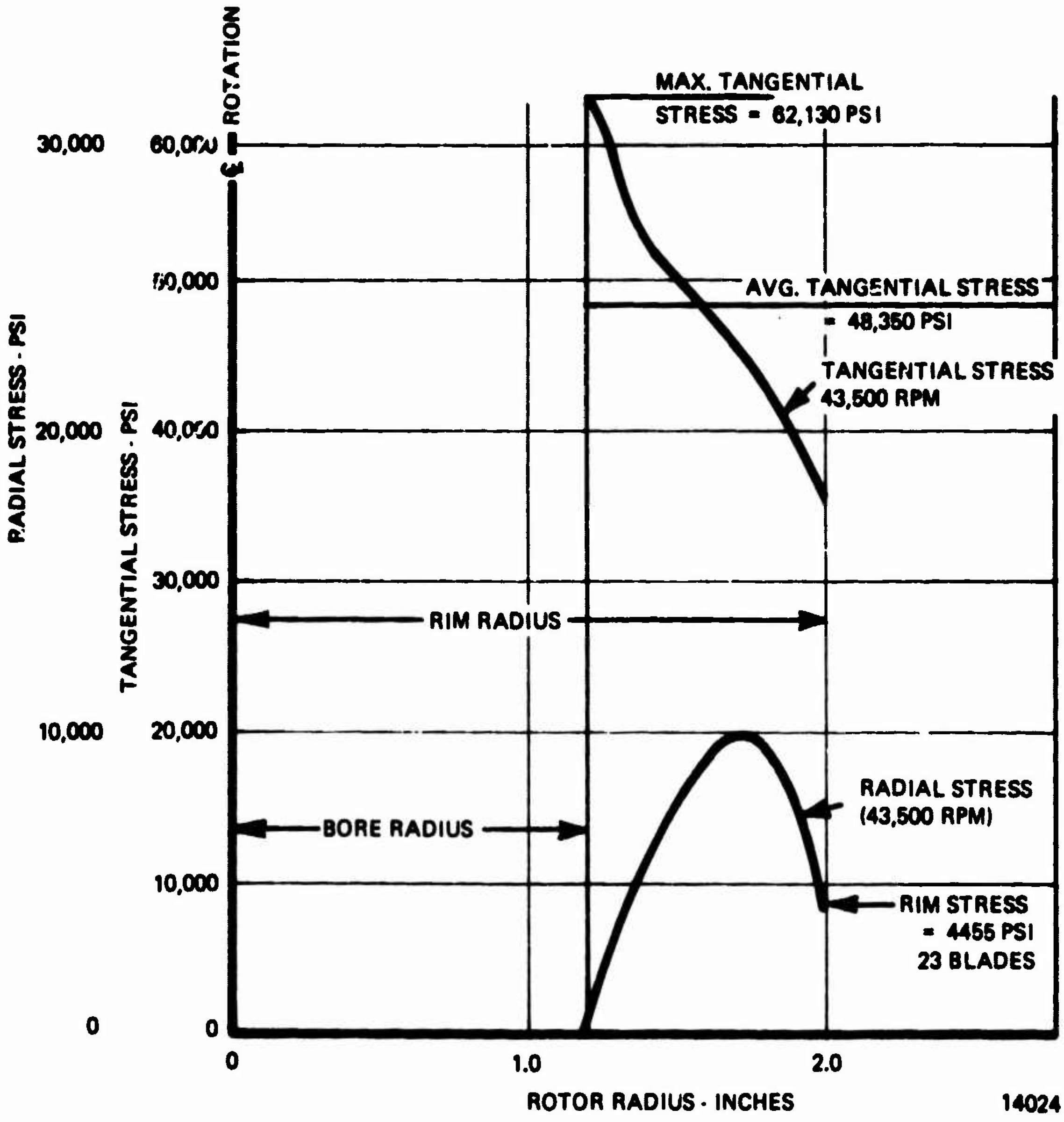

Figure 6. Tangential and Radial Stress Versus Gas Generator Rotor Radius

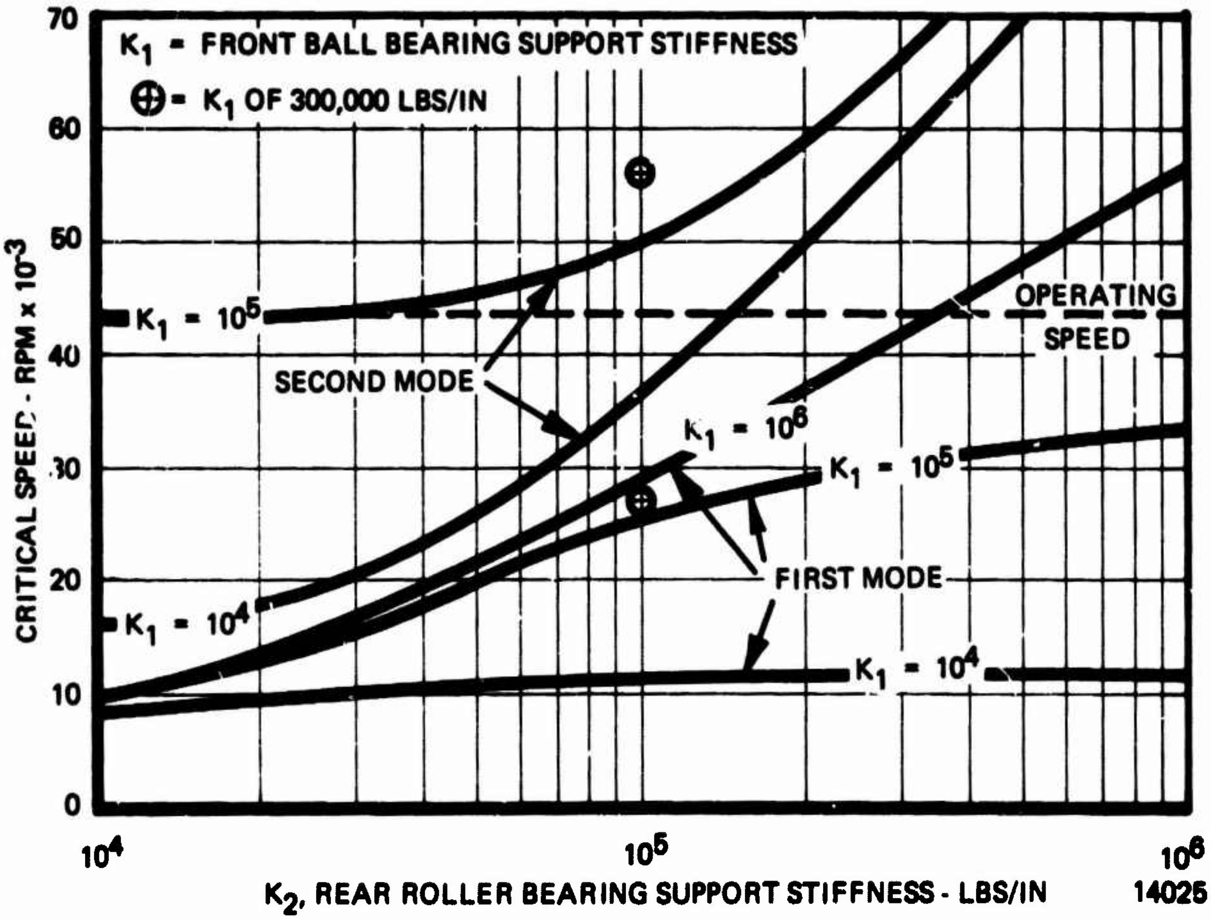

Figure 7. Gas Generator Shaft Critical Speed Versus Bearing Support Stiffness

The power turbine rotor assembly (Figure 8) consists of an investment cast Inconel 713LC turbine rotor keyed to the Greek Ascoloy shaft and retained by a self-locking nut. The stress analysis on the power turbine rotor was conducted at 30 percent over the design operating speed to allow for the overspeed condition which will occur upon disengagement of the clutch when the main engine ignites. The radial and tangential stresses versus rotor radius are plotted on Figure 9 for 37,700 rpm. The rotor has a predicted burst speed of 54,600 rpm which provides a margin of safety of 0.88 over design speed and a margin of safety of 0.45 for the 30 percent overspeed.

The power turbine Greek Ascoloy shaft was subjected to critical speed analysis using varying bearing support stiffnesses with the results plotted on Figure 10. Selection of the bearing support stiffnesses similar to those used for the gas generator shaft is indicated on the graph. These stiffnesses indicate that the first critical occurs 34 percent under the operating speed, and the second critical occurs 34 percent over the operating speed.

GEARBOX

The gearbox of the jet fuel starter (Figure 11) consists of the two-stage reduction gearing, the overrunning clutch, the power output shaft, the accessory drive train, the main shaft thrust bearings, the gear bearings and the lubrication system, all housed within the front compartments. The two gear stages provide a 10:1 speed reduction to produce the necessary output speed, with peak power being supplied just prior to the 3,000 to 3,500 rpm starter cutout. The gears have been designed, using design factors which allow for the use of unground gears. These gears are oversized compared to aircraft quality gears; however, the elimination of the requirements for supercritical finishes contributes to achieving the cost objectives.

The accessory drive train uses face and spur gear sets which eliminate the critical alignment problems associated with bevel gear sets. Machining of the housing is facilitated by these lessened requirements. The low rotor rpm of both shafts permits the use of low speed bearings with a simplified lubrication system. All gears and bearings are splash-lubricated by the oil from the sump created by the front compartment. This lubrication system eliminates the usual pressure and scavenge oil pumps, oil lines, passages, tank jets, coolers, filters, and regulating and anti-leak valves normally associated with long-life propulsion gas turbine engines.

COMPRESSOR

The compressor is the heart of all gas turbine engines, and as such, is a major portion of any engine development program and is also a significant part of the recurring labor and material cost in conventional engines. The compressor for the jet fuel starter (Figure 12) is an existing Teledyne CAE design that has been fabricated and rig tested to establish its performance characteristics.

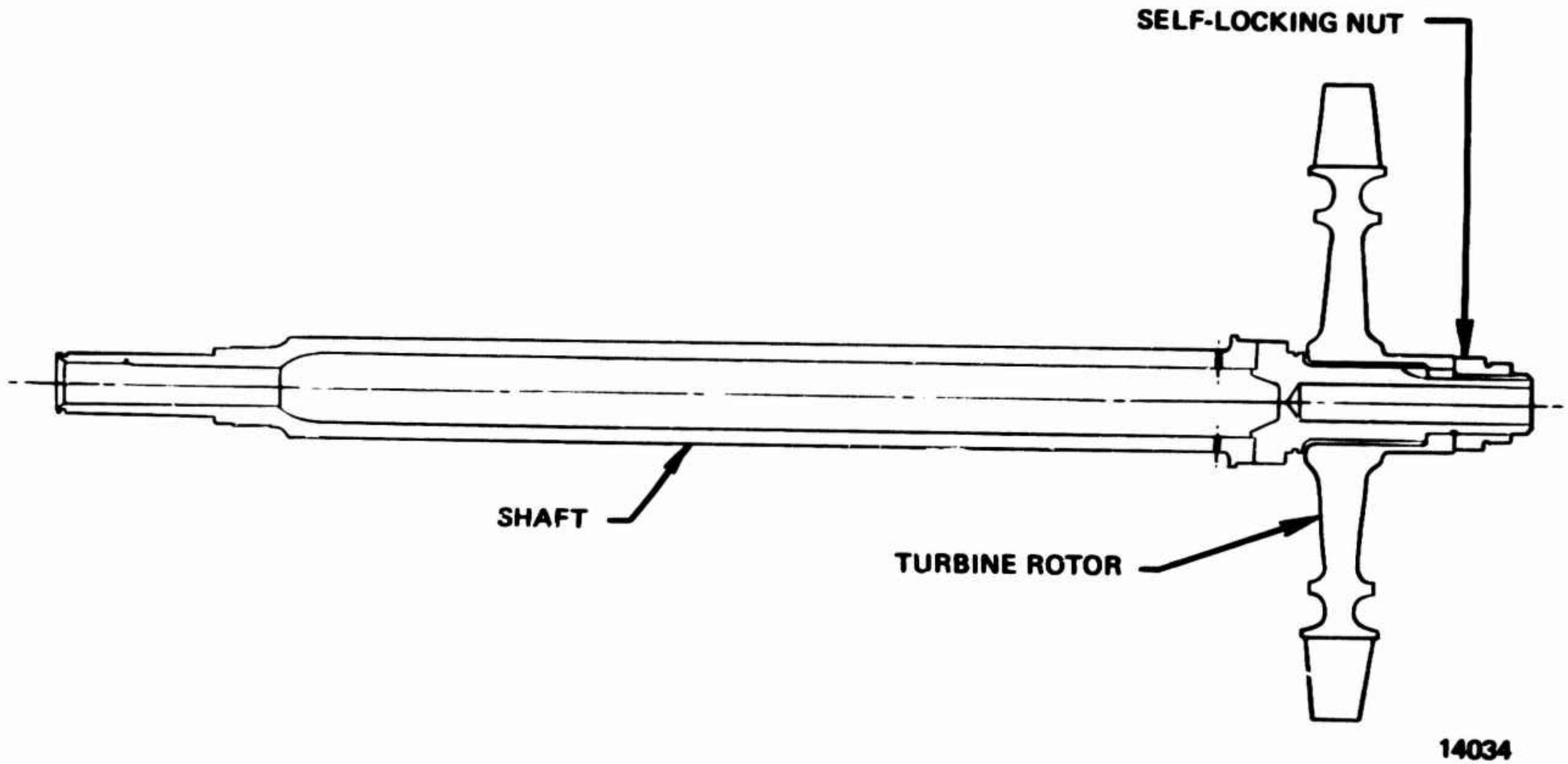

Figure 8. Power Turbine Rotor.

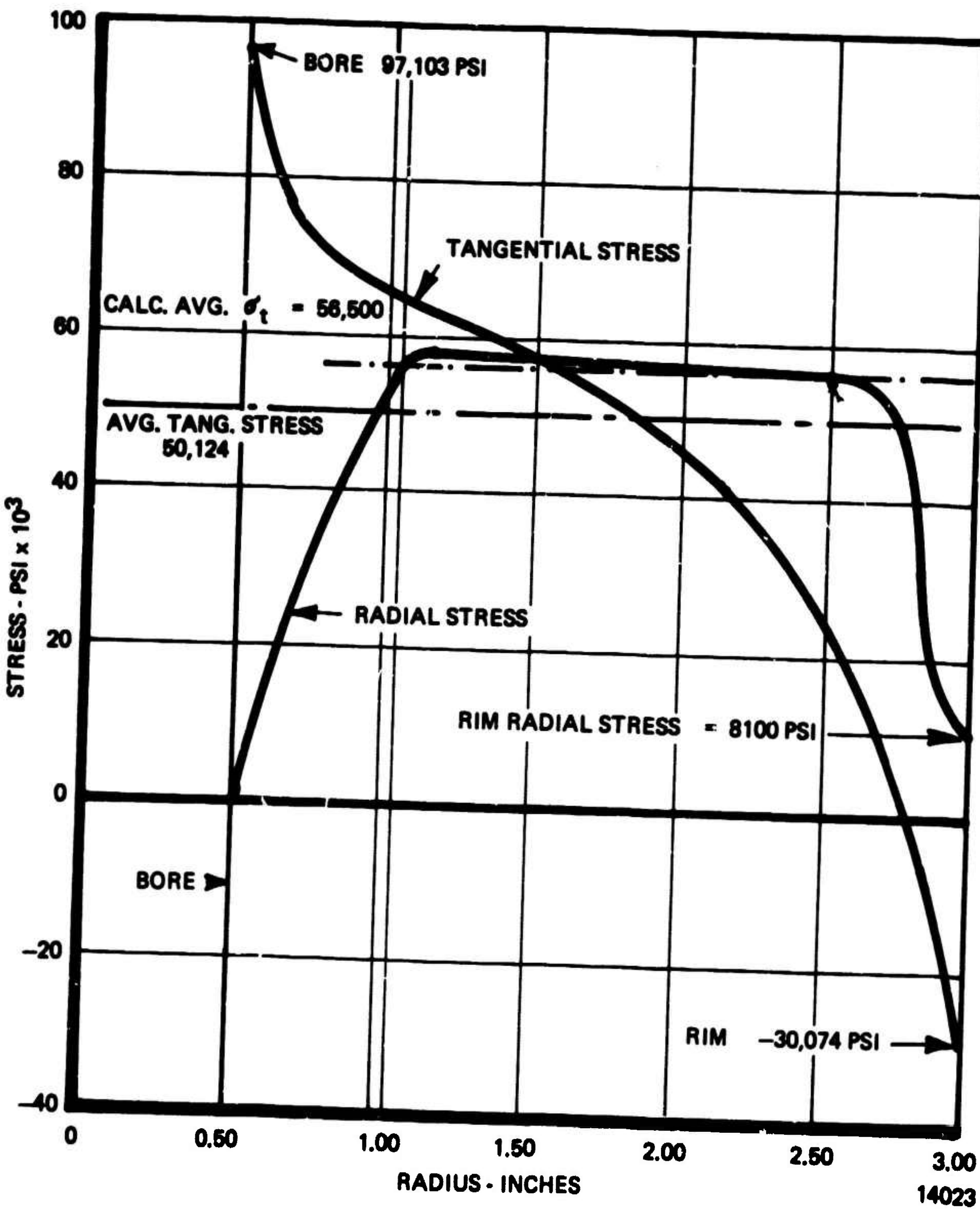

Figure 9. Tangential & Radial Stress Versus Power Turbine Rotor Radius.

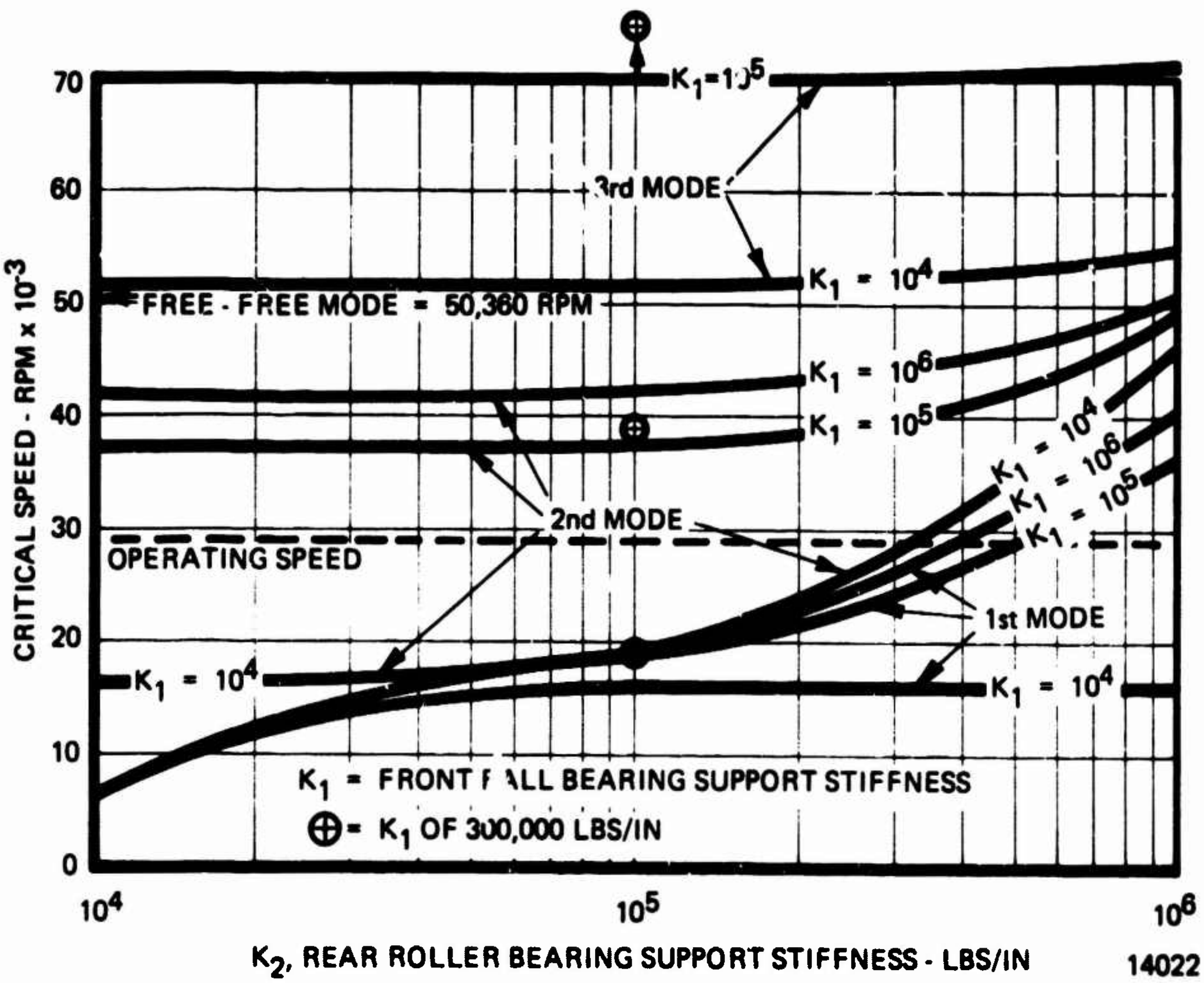

Figure 10. Power Turbine Shaft Critical Speed Versus Bearing Support Stiffness.

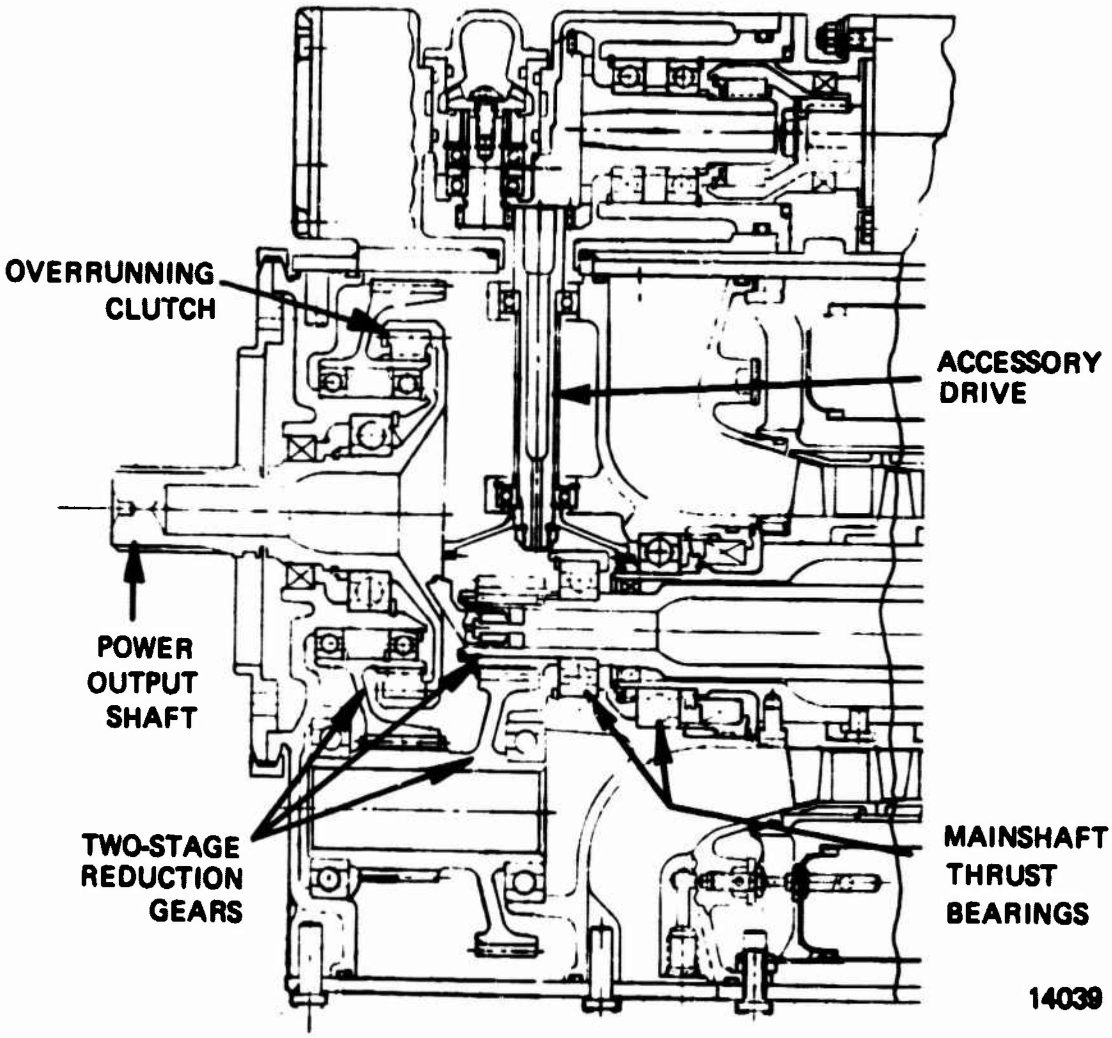

Figure 11. JFS206 Gearbox.

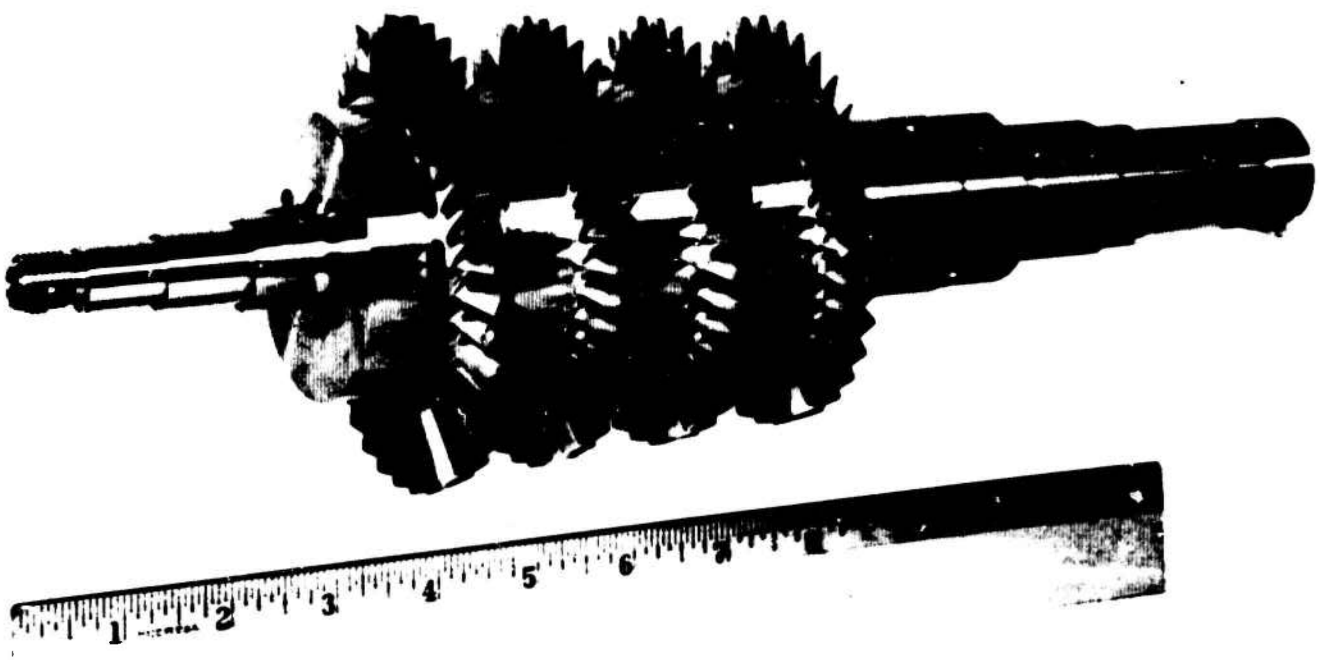

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Figure 12. Four-Stage Axial Compressor Rotor Ready for Installation into the Compressor Test Rig.

The compressor map (Figure 3) has been developed from the test rig. The low-speed compressor design (860 ft/sec tip speed) provides the capability for a large diameter through-shaft for two-shaft engines. As an added benefit, the low stress levels permit the use of low cost automotive type aluminum die castings. The compressor efficiency has been degraded to 80 percent, as discussed in the performance section, thereby providing additional latitude for compressor changes to suit the die casting process.

COMBUSTOR

Sizing of the jet fuel starter combustor indicates that loading parameters, while somewhat high, are within demonstrated Teledyne CAE vaporizer combustor experience. A tabulation of several combustor parameters for the jet fuel starter combustor is given in Table 1. Five parameters are of prime interest: (1) heat release rate, (2) dwell time, (3) aerodynamic loading, (4) pressure loss, and (5) combustion efficiency.

The inter-relationship of these parameters is shown in Figures 13 through 15 for several Teledyne CAE combustors developed for lift engine and Advanced Turbine Engine Gas Generator (ATEGG) applications. The jet fuel starter combustor design point is shown for reference.

Figure 13 correlates combustion efficiency with aerodynamic loading and illustrates the fall-off in efficiency that can occur with increasing loading. This parameter indicates the JFS206 combustor to be quite highly loaded. However, it should be noted that the lift engine combustors were not only loaded heavily aerodynamically, but also in heat release rate and dwell time. This is illustrated in Figures 14 and 15. Figure 14 relates combustion efficiency with the product of dwell time and the square root of the pressure drop, and illustrates the extremely short dwell time of other engine combustors relative to the JFS206 combustor. Consequently, since dwell time has a strong influence on efficiency, the JFS206 combustor is within the range of advanced technology engine combustors which have demonstrated efficiency levels in excess of JFS requirements.

Also, as shown in Figure 15, other engine combustors have combined high heat release rates with the high aerodynamic loadings and short dwell times illustrated in Figures 13 and 14. The required heat release rate of the JFS206 combustor is substantially less than the demonstrated heat release rates of these engine combustors. The lower heat release rate combines with the longer dwell time to significantly ease the overall loading picture of the JFS combustor. The primary combustor development problem will be to achieve a satisfactory exit temperature profile with only three fuel nozzles and "T canes".

TURBINES

The gas generator turbine speed is fixed by the compressor requirement of 43,500 rpm. The rotor exit discharge critical velocity ratio was selected as low as possible, 0.319, with zero swirl to minimize the transition duct losses

TABLE 1

JFS206 COMBUSTOR PARAMETERS

Airflow - lb/sec.	2.228
Inlet Pressure - psia	41.99
Inlet Temperature - ^{o}R	744
Overall f/a	0.0245
Primary Volume - ft^3	0.0753
Total Volume - ft^3	0.1232
Mean Path Length (L) Total - ft	0.492
Primary Zone Intensity - BTU/Hr ft^3atm	16.8×10^6
Total Intensity - BTU/Hr ft^3atm	9.76×10^6
Aerodynamic Loading - lb/sec ft^3 atm^2	2.214
Temperature Rise - ^{o}F	1516
Reference Velocity - ft/sec	58.91
Residence Time (τ) - millisec.	8.43
Pressure Drop - %	5.0
Combustion Efficiency - %	95.0

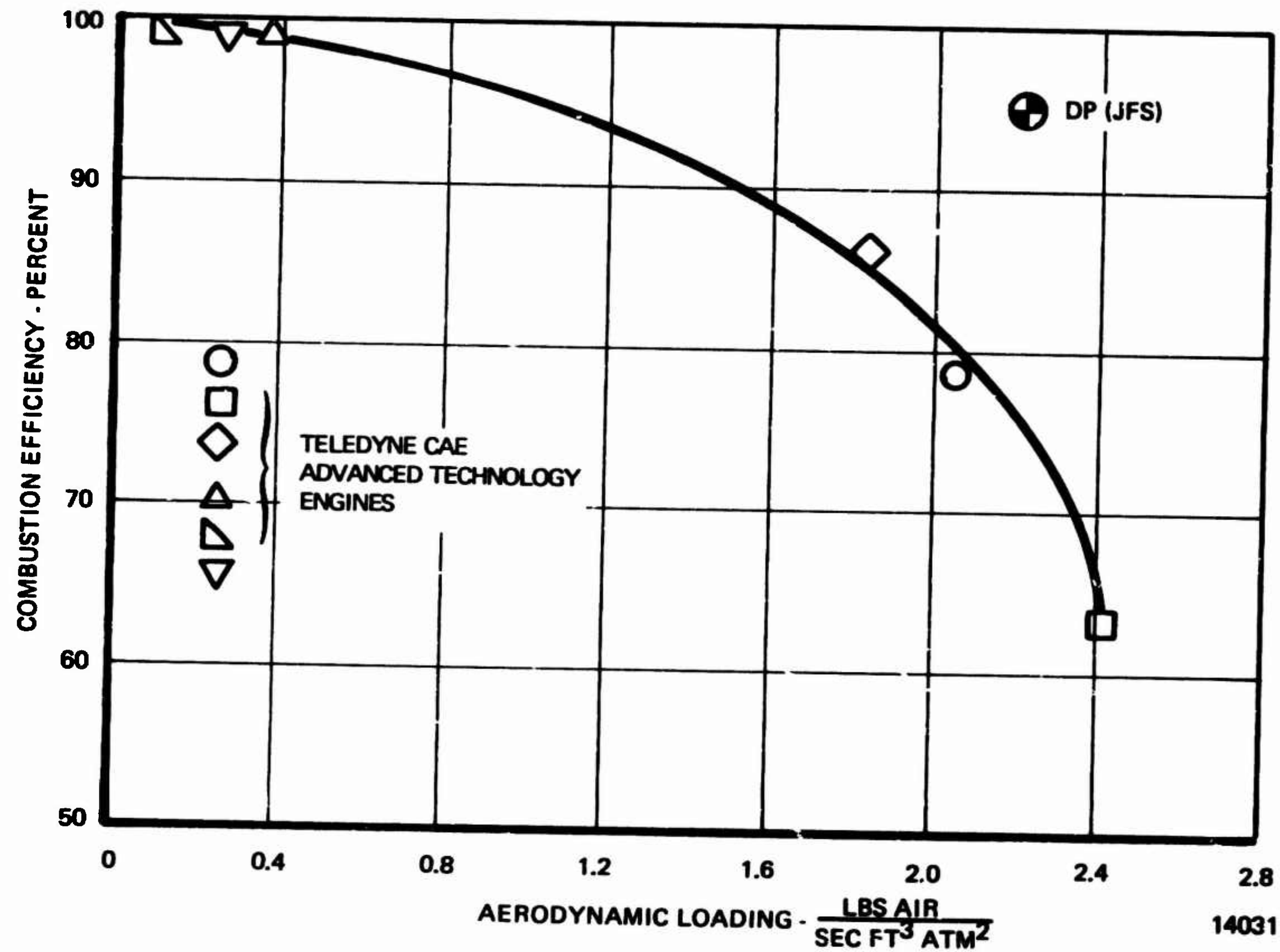

Figure 13. Correlation of Combustion Efficiency to Aerodynamic Loading.

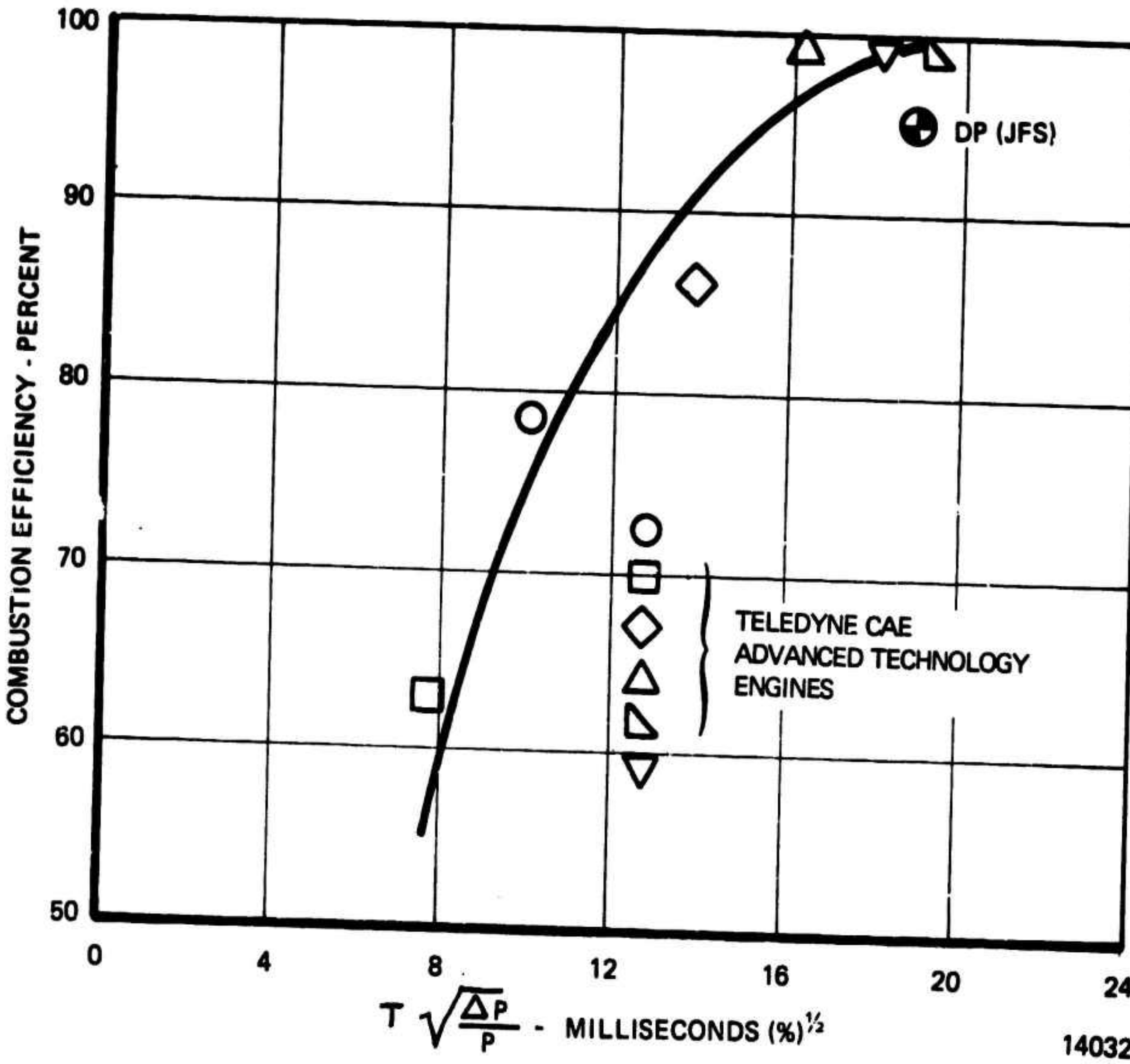

Figure 14. Correlation of Efficiency, Dwell Time and Pressure Drop.

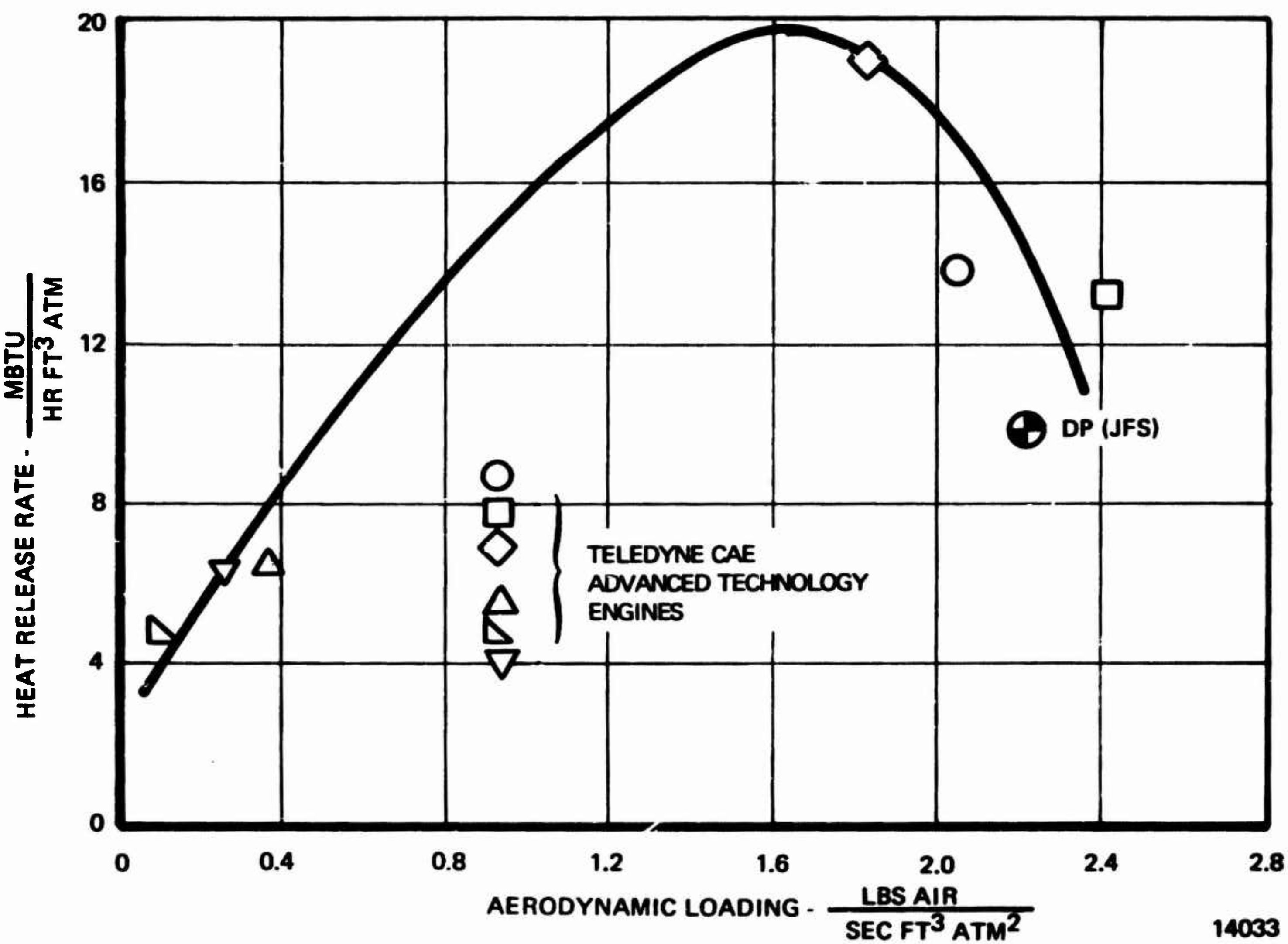

Figure 15. Relation of Heat Release Rate to Aerodynamic Loading.

between the gas generator and power turbines. The axial chord of the nozzle was set at 1.5 inches to satisfy the combustor flow requirement: one half of the combustor flow is supplied through hollow nozzle vanes to the outer half of the combustor. A total vane cross-sectional area of 6.2 square inches is required to limit the total-to-total combustor pressure drop to 5.0 percent. To achieve this cross-flow area, twelve vanes are required, with a solidity in excess of optimum. The airfoils are lightly loaded however, and the efficiency penalty is minor.

A relatively large axial chord of 0.62 inch on the rotor along with a specified trailing edge thickness no less than 0.025 inch permits ease of castability of the integral wheel. A generous running tip clearance of two percent of the blade span should also allow the wheel to be cast to diameter with minimal machining. The preliminary velocity triangles of the described gas generator turbine are presented in Figure 16, and the flowpath is provided in Figure 17. The flow and work coefficients (Table 2), give this turbine a high efficiency potential. And when the simple geometrical constraints are imposed for castability, the performance is still predicted at 82.5 percent. The rotor hub blade stress is 26,143 psi with a blade temperature of less than 1650°F, giving a stress rupture IN 713C life in excess of 800 hours. Some of the gas generator turbine geometrical constraints for low cost and ease of manufacture are:

Vane Assembly	
Number of Nozzle Vanes	12
Axial Chord - in.	1.50
Trailing Edge Thickness - in.	0.035
Thickness to Chord Ratio	0.20
Rotor	
Number of Blades	37
Axial Chord - in.	0.62
Trailing Edge Thickness - in.	0.025
Thickness to Chord Ratio	0.13
Running Clearance - in.	0.020

The power turbine was sized with a containment ring sized not to exceed the combustor casing (engine) diameter of 10.0 inches. The rotational speed was then set as low as possible consistent with moderately high turbine aerodynamic loading to achieve the cycle efficiency requirement of 80 percent. As with the gas generator, the power turbine geometrical constraints were selected for ease of castability, simplicity, and low cost. A low rotor discharge critical velocity ratio of 0.323 was also required to minimize leaving losses. With this low leaving velocity, a direct dump is allowable and the cost of a diffuser is eliminated. Some of the power turbine geometrical constraints for low cost and ease of manufacturability are:

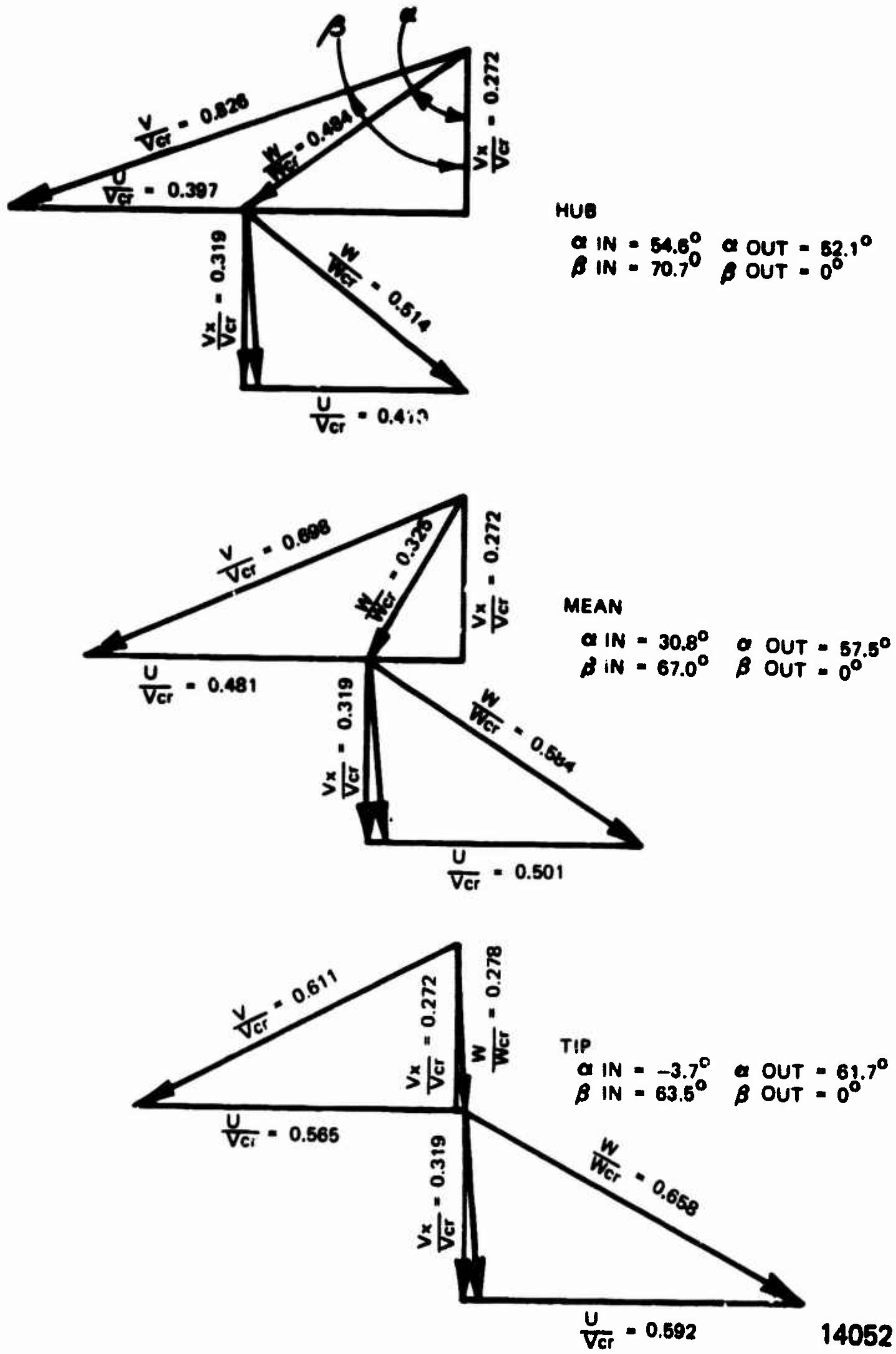

Figure 16. Gas Generator Turbine Velocity Triangles.

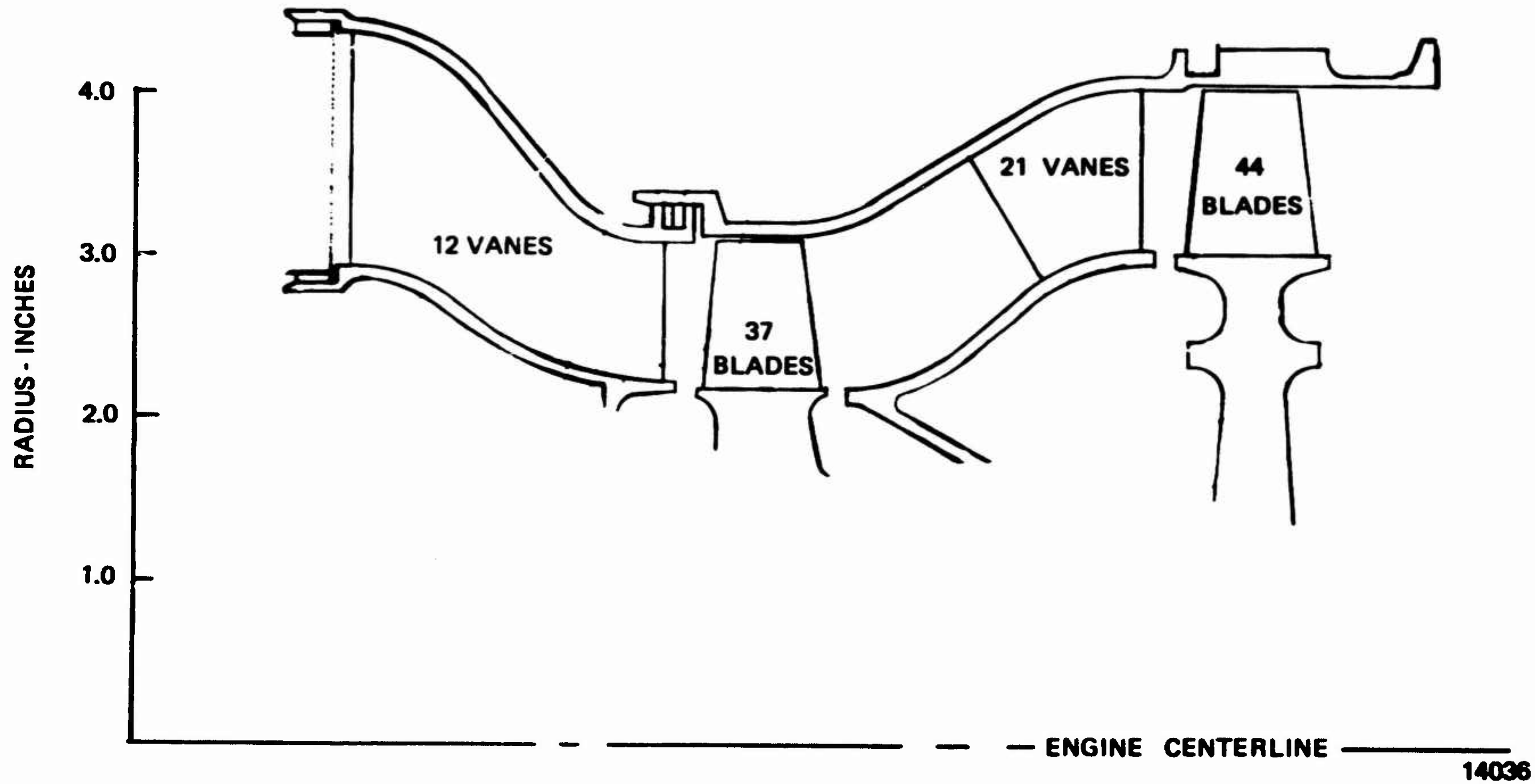

Figure 17. Jet Fuel Starter Turbine Flow Path.

Vane Assembly	
Number of Nozzle Vanes	21
Axial Chord - in.	0.95
Trailing Edge Thickness - in.	0.035
Thickness to Chord Ratio	0.15
Rotor	
Number of Blades	44
Axial Chord - in.	0.73
Trailing Edge Thickness - in.	0.025
Thickness to Chord Ratio	0.13
Running Clearance - in.	0.030

TABLE 2

TURBINE AEROTHERMODYNAMIC REQUIREMENTS

	Gas Generator Turbine	Power Turbine
Inlet Temperature T, °R	2260	2074
Inlet Pressure P, psia	39.9	24.48
Gas Flow W, lbs/sec.	2.283	2.283
Rotative Speed N, rpm	43500	29000
Flow Parameter $(WN/\delta\ 60)\epsilon$, lbs-rev/sec.^{2}	634	688
Specific Work ΔH, BTU/lb.	54.24	47.89
Referred Work $\Delta H/\theta cr$, BTU/lb.	12.91	12.33
Referred Speed $N/\sqrt{\theta cr}$, rpm	20524	14714
Total-To-Total Efficiency, %	82.5	80.0
Referred Flow $(W\sqrt{\theta cr}/\delta)\epsilon$, lbs/sec.	1.85	2.81
Flow Coefficient Vx/Um	0.601	0.674
Work Coefficient $gJ\Delta H/Um^2$	1.34	1.57

A power turbine rotational speed of 29,000 rpm results in a predicted efficiency of 80.1, which meets the cycle requirement, with these geometrical constraints. The velocity triangles are given in Figure 18 and flowpath in Figure 17. Mach numbers and turning angles are moderate and performance targets should be readily achievable.

CONTROL AND STARTER SYSTEM

Operation

The control system (Figure 19) provides both control of the engine and a

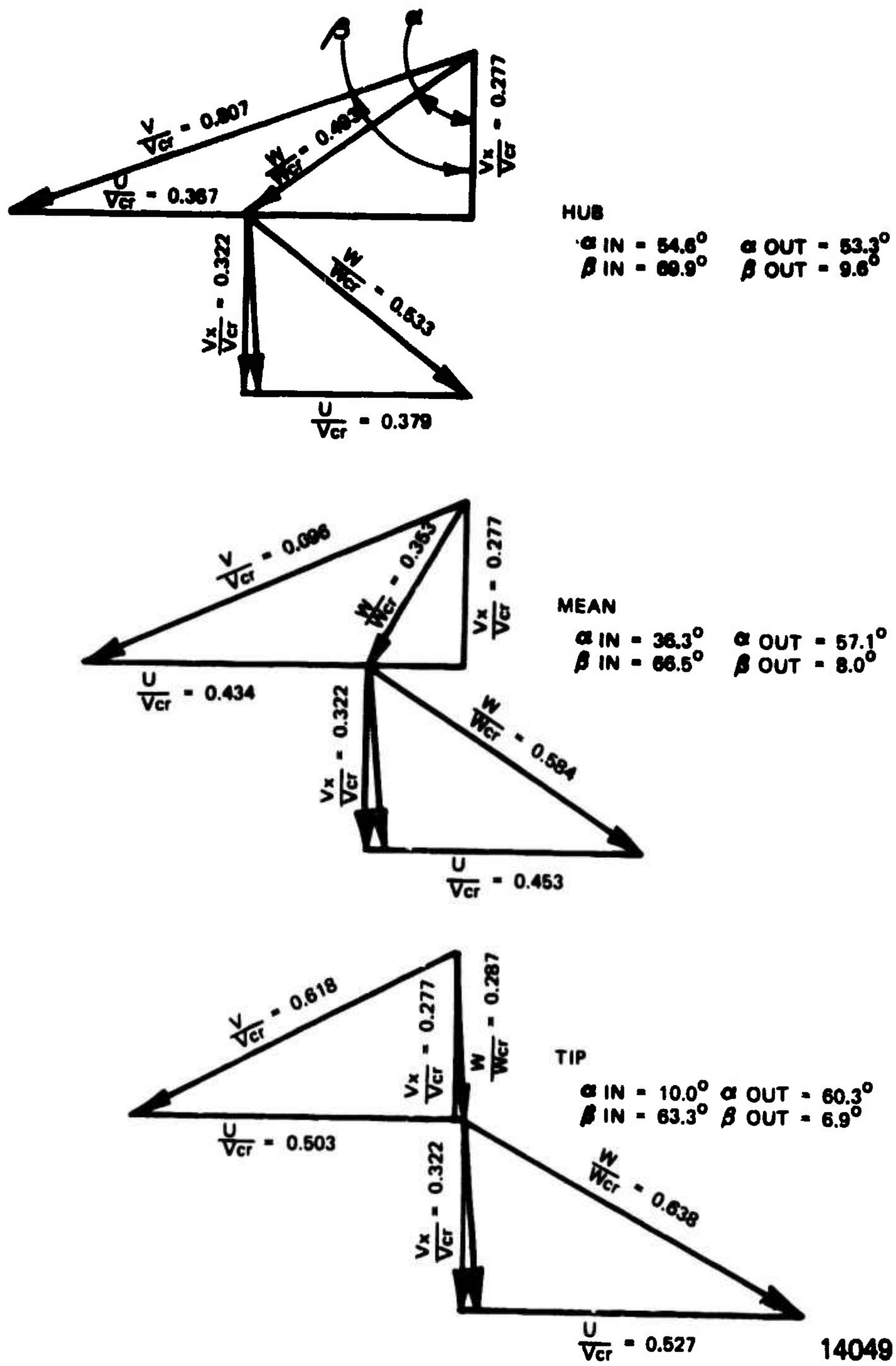

Figure 18. Power Turbine Velocity Triangles.

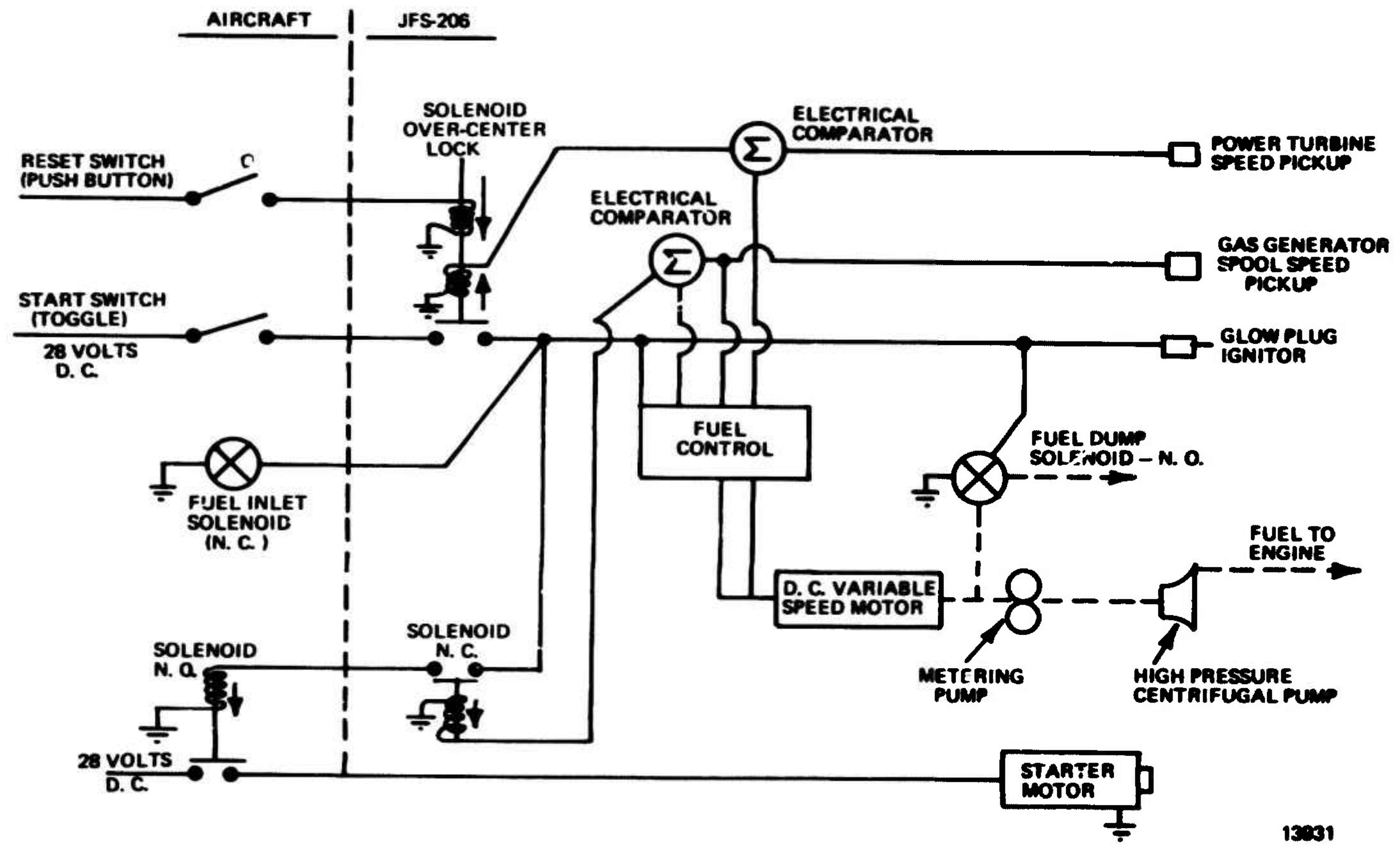

Figure 19. JFS206 Control System Schematic.

logical sequencing of events to assure proper performance of the overall system. The following narrative describes the basic cycling of the system from startup to shutdown. (Refer to Figure 19)

<u>Startup</u>

A. The reset button is pushed to eliminate the effect from the previous shutdown. The over-center solenoid is energized to the on position.

B. Moving the start switch to the On position initiates a series of events.

   1. The fuel inlet solenoid is powered open.

   2. The fuel dump solenoid is powered closed.

   3. The fuel control is turned on.

   4. The glow plug igniter is turned on.

   5. The electrical starter motor is provided with a low resistance current path on a separate line by means of two solenoid switches. The first low current switch is normally closed and in this position closes the second high current switch which is normally open. When the two switches are closed, the starter motor cranks the JFS206 engine to 60 percent speed on the gas generator spool.

   6. When the gas generator spool attains 60 percent, a signal from a speed pickup is compared to a predetermined value from the fuel control. The low-current solenoid to the starter motor opens which in turn opens the high-current solenoid switch. This shuts off the starter motor, thus preventing excessive running of it after the JFS206 has attained self-sustaining speed.

<u>Acceleration</u>

A. During this portion of the cycle, the gas generator accelerates from 60 percent to 100 percent speed and is held at this speed by the fuel control system. This is accomplished by a closed-loop speed sensing system in which gas generator spool speed is sensed and compared to a predetermined value. This comparision is then translated into a drive speed signal and applied to the variable speed D.C. motor. This motor drives a constant displacement pump that provides metering of the fuel to the engine as a function of speed.

B. As the gas generator increases in speed, the power turbine increases in speed and provides the direct cranking power to the driven engine.

At a predetermined power turbine speed, a speed signal comparator transmits a shutdown signal to the over-center solenoid switch. Opening of the switch contacts interrupts the electrical power supply to the entire system.

Shutdown

A. Engine shutdown is triggered by the power turbine speed comparator signal. This signal indicates that the driven engine has attained sufficient speed to be self-sustaining. When this signal interrupts the main electrical power supply, a number of events are initiated:

1. The glow plug igniter is turned off.

2. The fuel control is turned off.

3. The fuel dump solenoid is opened.

4. The fuel inlet solenoid is closed.

5. The over-center solenoid is powered open and cannot be closed until the reset button is pushed to initiate a start.

B. The JFS206 then decelerates to a stop and is inactive until the start sequence is repeated.

FUEL CONTROL FUNCTIONAL DESCRIPTION

The fuel control system is divided into two basic subdivisions of electronics and hydraulics. A brief description of the major components and/or divisions follows.

ELECTRONICS

The fuel control electronics portion is basically an isochronous governor which uses speed signals from both the high- and low-pressure spools as well as a speed signal from the constant displacement fuel pump to generate a control signal for the variable speed D.C. motor. The gas generator signal is used to reduce the predetermined 100 percent speed demand signal until constant speed is achieved. The control uses a sequential series of select gates in a speed select network to provide the final D.C. motor drive signal. The inputs into this network include:

A. Maximum Wf (preset)

B. Starting Ramp Wf Rate (Generated Internally)

C. Topping Governor Wf (from NHP)

D. Minimum Wf (Preset)

E. Fuel Shutoff (from NLP)

In addition, the control provides speed signal values for both speed comparators to shut off the electrical starting motor at 60 percent gas generator speed and the entire system when the power turbine achieves 100 percent speed.

HYDRAULICS

The hydraulics section consists of a positive displacement pump, a variable speed D.C. motor, a constant pressure rise regulator, and a vapor core high pressure pump. The D.C. motor is driven and controlled by the output from the electronics and is independent of gas generator spool speed. The fuel from the pump passes through an orifice controlled by the constant pressure rise regulator thereby providing a very reproducible and predictable measure of fuel in proportion to pump speed. The high pressure vapor core pump is driven by the gas generator and provides sufficient pressure to overcome CDP plus fuel orifice pressure drops in the combustor.

SECTION III

DESIGN ASSURANCE

APPROACH

During the study phase of the low-cost jet fuel starter program, Teledyne CAE conducted an on-going assessment of its design-assurance (or "utility") attributes.

The study approach considered reliability, maintainability and system safety as related objectives. Their worth or "utility" had to be evaluated in concert with the low-cost, adequate performance and user convenience objectives of the program. We, therefore, selected the Failure Mode Effect Analysis (or FMEA) technique, because it can be expanded to answer such questions as:

1. Will the starter provide adequate reliability for the 2000 starts between overhaul "mission"?

2. Should maintenance aids, such as failure indicators, be included, and would their added cost be justified for a prospectively high-reliability device?

3. Do the modes of failure present hazards that are unacceptable by virtue of probability or consequence?

4. Would reliability enhancing design features improve the overall cost of ownership?

The results of the FMEA are discussed in the following subsection. In summary, they confirm that the basic approach will provide acceptable utility. However, it was also found that acceptably accurate forecasts of user life cycle costs require the design definitions and cost data that will be more readily acquired in the demonstrator engine development program.

RELIABILITY ANALYSIS

A preliminary reliability analysis of the JFS206 has been accomplished. The calculated result is based on conventional methods for assessing the reliability of individual mechanical, electrical and electronic components. Also, the estimated failure rates for electronic parts are based on the use of "good commercial" or industrial-quality parts, with no recourse to Mil-Spec type screening or reliability conditioning (burning-in) at the part level. As the JFS design becomes progressively defined, the value of a control-assembly burn-in will be evaluated.

Also, because of the cyclic duty cycle, the mean-time between failure data has been converted to a failure per overhaul cycle basis. The results of the analysis are shown in Table 3, together with recommended design goal values and

TABLE 3 . JET FUEL STARTER-RELIABILITY PREDICTION
TELEDYNE CAE MODEL JFS206

ITEM (i)	ITEM DESCRIPTION	QNTY Per Sys. (N)	ESTIMATED FAILURES IN 2000 STARTS (25 OPER. HR.) (λt)	ADJUSTED FAILURE ($N \lambda t$)
	Note: 1) Overhaul Life = 25 Hr. or 2000 Starts 2) Components are good-commercial or industrial quality 3) Mi = Component MTBF (Hr.)			
1	Bare Engine (M_1 = 1200 Hr)	1	.0206	.0206
2	Starter Ass'y, Electric (M_2 = 1500)	1	.0165	.0165
3	Fuel Control, Solid State (M_3 = 3000)	1	.0083	.0083
4	Fuel Control, Electric Pump M_4 = 1000)	1	.0247	.0247
5	Speed Pick Up's (M_5 = 10,000)	2	.0025	.0050
6	Solenoid Valve - Fuel Dump (M_6 = 28,000)	1	.0009	.0009
7	Solenoid, NC (Application; $M_7 = 3.3 \times 10^5$)(K = .1)	1	.0001	.0001
8	Solenoid, Over Center, ($M_8 = M_7$)	1	.0001	.0001
9	Lines, Harness, Conn. $.15 \times (N \lambda t_2 + \cdots N \lambda t_B)$	-	.0083	.0083
	SUB-TOTAL: Controls & Accessories	-	-	.0639
	TOTAL: Jet Fuel Starter			.0845

Estimated (Design Goal)
Reliability for Total TBO of 2000 Starts = .92
Estimated (Design Goal)
Reliability for One Flight/One Start = .999
("Dispatch-Reliability")

Recommended Specification Values:
Reliability for 2000 Starts = .90, Reliability for One Start = .995

specification requirements for follow-on phases of the jet fuel starter development. These values are:

1. Reliability for one overhaul cycle (2000 starts).
   Objective = 0.92, Requirement = 0.90

2. Reliability for one start
   Objective = 0.999, Requirement = 0.995

MAINTAINABILITY

Maintainability factors for the JFS206 will vary as a function of, 1) specific aircraft installations; 2) the using activities maintenance doctrine; and 3) the capability of ground equipment.

The aircraft installation will largely determine the time to repair or replace a suspect starter and will also establish the feasibility of replacing JFS accessories on aircraft.

The maintenance doctrine will determine the intermediate maintenance level or off-aircraft maintainability. For example, one doctrine could require that any suspect unit be returned to a depot, while another would require tear-down and replacement at a Jet Engine Base Maintenance facility. The appropriate doctrine should be determined by conducting an Optimum Repair Level Analysis (ORLA).

The capability of support equipment will affect the time to diagnose, repair (if necessary) and return a suspect unit to service.

The foregoing consideration requires some assumptions about the maintenance environment of the JFS206 in order to estimate its maintenance index. These are:

a) In most applications, the unit will not be accessible for on-aircraft repair.

b) Off-Aircraft repair will be accomplished at a Jet Engine Base Maintenance Facility.

c) Control and accessory components will be repaired by replacement for an active maintenance time of one hour.

d) Bare engine component repairs will also be accomplished by replacement after an engine tear-down inspection, for an active maintenance time of two and one-half hours.

The maintenance task times must be weighted with their relative frequency. For that purpose, the reliability analysis indicates that there will be three control and accessory actions for every action affecting the Bare Engine. The overall index is therefore calculated from:

$$Mct = (3 \times 1 \text{ hour} + 1 \times 2.5 \text{ hours}) / 4 = 1.375 \text{ hours.}$$

Where Mct = Mean Corrective Maintenance time.

HAZARD ANALYSIS

The safety analysis considered all failure modes classically exhibited by small turbo-machinery. The design has incorporated containment rings around critical areas to absorb energy and retain fragments should catastrophic failure of rotating components occur. Low stresses and temperatures inherent in the design have contributed to reducing hazardous failure probabilities. The hazard analysis is part of the integrated FMEA described in tne next subsection.

FAILURE MODE EFFECT ANALYSIS AND MAINTENANCE CONSEQUENCES

This analysis provides a combined chart format as shown in Table 4 for completely identifying the consequences of a failure on maintenance costs and safety hazards. The failure modes considered are the historically typical ways in which a turbine engine can fail. The net effect upon the system is identified. The features of the JFS206 which preclude the failure mode are then related in the Safety Considerations and Compensating Provisions columns. The lowest levels of maintenance capable of correcting the system are listed in the Repair Level column. Components which must be removed to access the "failed" portion are identified and listed under the appropriate components column. The maintenance sequence diagram of Figure 20 complements the maintenance consequence analysis to describe maintenance tasks.

A separate index of manhours-per-theoretical "failure" case analysis was initiated. And although very low manhours expenditures were arrived at, the analysis is felt to be premature because of installation sensitivity.

Design variations in mounting of the JFS206 will affect the organizational maintenance task time for all failure modes explored. However, the design for maintenance concept at Teledyne CAE has resulted in an innovative feature which employs radial pins to secure the components of the JFS. The pins are retained in place by overlapping surfaces in the rotor assembly and band clamps on the housing assemblies. This labor saving feature allows the maintenance mechanic to disassemble the entire JFS by releasing one or two band fasteners and separating the components in the order described by the maintenance sequence diagram (Figure 20). By this innovation, assembly procedures have been made comparatively less time consuming than with similar engines by simply assembling pieces in a definite order and latching up a single fastener to complete an assembly. The other classic features for low maintenance cost are also embodied in this Teledyne CAE design: simple fasteners, lowest possible number of fasteners, no special disassembly tools, small size and weight of components for "one-man" handling, and pieces that lock together during assembly. The cost of material for maintenance was analyzed and the costs found to be sensitive to production and volume costs.

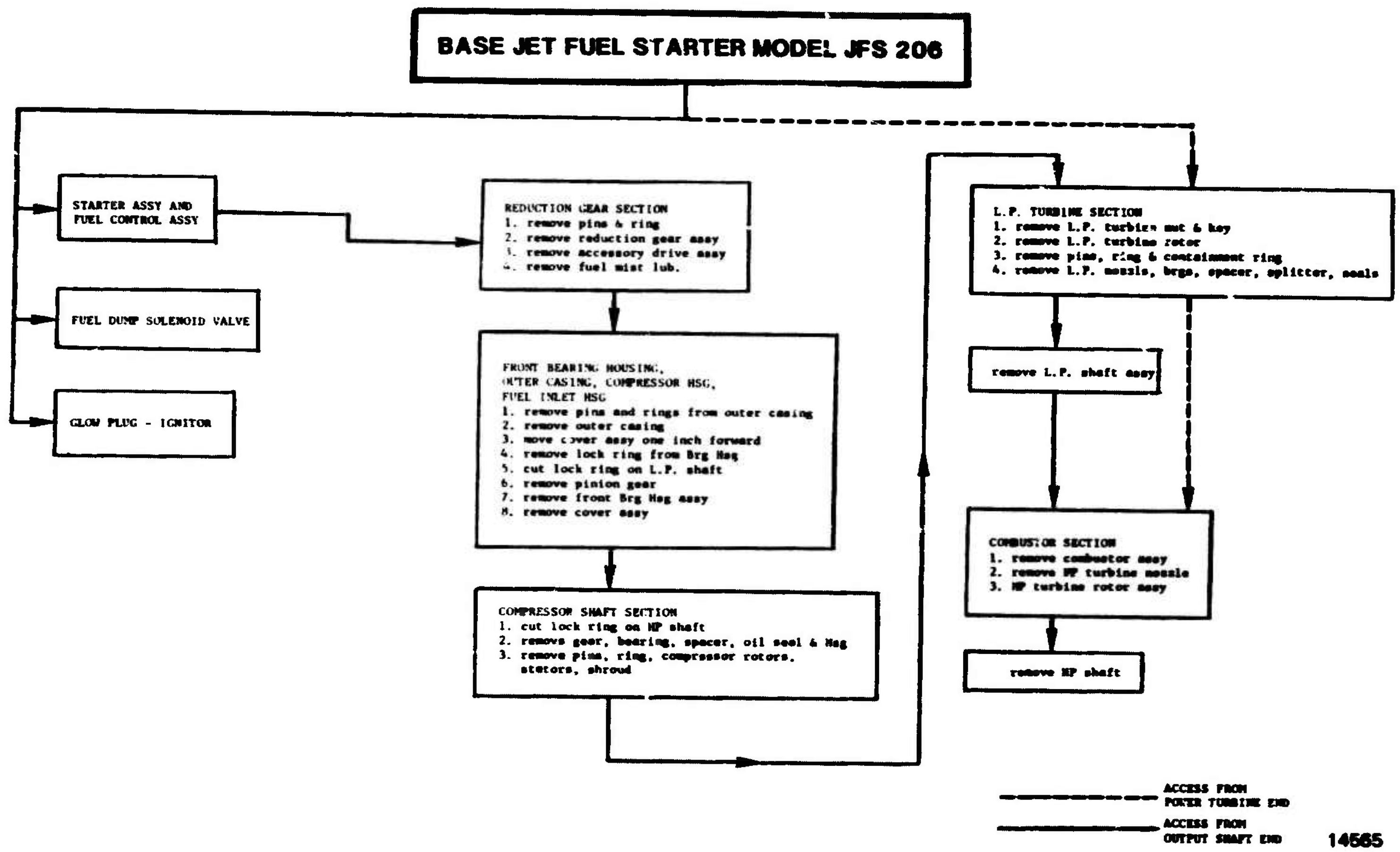

Figure 20. Jet Fuel Starter - Maintenance Sequence Diagram.

TABLE 4

FAILURE MODE EFFECT ANALYSIS AND MAINTENANCE CONSEQUENCE

ENGINE MODEL JFS-206

PROGRAM Jet Fuel Starter

SHEET 1 OF 2

COMPONENT NAME	COMPONENT PART NUMBER	FAILURE MODE		FAILURE EFFECTS		MAINTENANCE CONSEQUENCE			MAINT. COST		SAFETY CONSIDERATIONS	COMPENSATING PROVISIONS	REMARKS
		CASE	DESCRIPTION	ENGINE	SYSTEM	REPAIR LEVEL	COMPONENTS REMOVE & REINSTALL	COMPONENTS AFFECTED & REPLACED	MH/ TASK	MAT'L $ COST			
Compressor Rotor		1.1	Blade Crack & Section Separation.	Rotor Unbalance Blade Rub, RPM Loss.	Vibration, some power loss with main engine start dependent on % blades separated.	Org.	Starter	Starter			Shroud Containment	Low stress levels due to low operating RPM.	
						Inter.	Fuel Control Reduction Gear Section Frnt. Brg. Hsg. Outer Casing, Compressor Hsg Fuel Inlet Hsg Compressor Shaft Section	Compressor Rotors					
		1.2	Burst	Secondary damage, Starter inoperative	No start, parts contained within outer casing.	Same as 1.1	Same as 1.1	Same as 1.1			Steel shroud containment of aluminum parts.	Low stress levels due to low operating RPM.	
Shaft		2.1	Thrust Bearing Failure.	RPM decrease Unbalance	Vibration, power loss, possible seizure, aborted start.	Org.	Starter	Starter			Overrunning Clutch would disengage.	Pot Lube System assures adequate lube when sump is full. Low operational RPM & Temp.	
						Inter.	Fuel Control Reduction Gear Section Front Brg. Hsg.	Front Brg.					
		2.2	Rear Bearing Failure.	RPM decrease, Shroud Rub, Unbalance	Same as 2.1	Org.	Starter	Starter			Same as 2.1	Waste Fuel Lube System cools & Lube Bearing with mist. Rear Brgs Designed to withstand more than 50% greater temp. stress than actual.	
						Inter.	LP Turbine Section	Rear Brg					
Combustor		3.1	Fatigue Cracks	No immediate effect	No Effect	Depot	L.P. Turbine Section L.P. Shaft Combustor Sectn	Combustor Weld			N/A	Repair at overhaul	
		3.2	Piece Breaks Off	Possible minimum Turbine Blade damage due to thin wall construction of combustor.	Minimal effect on performance, normally found at overhaul.	Same as 3.1	Same as 3.1	Same as 3.1			N/A	Repair at overhaul	

TABLE 4

(continued)

ENGINE MODEL SFS-206 PROGRAM Jet Fuel Starter SHEET 2 OF 2

COMPONENT NAME	COMPONENT PART NUMBER	FAILURE MODE		FAILURE EFFECTS		MAINTENANCE CONSEQUENCE			MAINT. COST		SAFETY CONSIDERATIONS	COMPENSATING PROVISIONS	REMARKS
		CASE	DESCRIPTION	ENGINE	SYSTEM	REPAIR LEVEL	COMPONENTS REMOVE & REINSTALL	COMPONENTS AFFECTED & REPLACED	MH/ TASK	MAT'L $ COST			
HP Turbine Rotor		4.1	Blade cracks Pieces Separate	Secondary damage to Nozzle & LP Turbine unbalance.	Vibration Power loss	Org.	Starter	Starter			Overrunning Clutch disengages, containment ring prevents secondary system damages & retains pieces.	Low stress levels short duration duty cycle.	
						Inter.	L.P. Turbine Section L.P. Shaft Combustor Section	HP Turbine Rotor LP Turbine					
		4.2	Yield	Tip rub	Power loss	Same as 4.1	Same as 4.1	Same as 4.1			Same as 4.1	Same as 4.1	
LP Turbine Rotor		5.1	Blade cracks Pieces Separate	Unbalance	Vibration Power loss	Org.	Starter	Starter					
						Inter.	LP Turbine Section	LP Turbine			Same as 4.1	Same as 4.1	
		5.2	Lock Nut failure	Rotor uncontained possible secondary damage.	Power loss Possible system damage.	Org.		Nut LP Turbine Rotor			Lock Ring Retention	Specified Torque at Assembly.	
Gear Train		6.1	Drive Gear Break	Fuel stops Engine shutdown	No Start	Org.	Starter	Starter			Low inertia forces, self containment of fragments.		
						Inter.	Fuel Control Reduction Gear Section	Drive Gear				Overrunning clutch protects system.	
		6.2	Output Gear Break	No Effect, to possible Gear Section Secondary Damage.	No Start Possible prime engine damage to Accessory Drive.	Org.	Same as 6.1	Output Gear			Same as 6.1	Low stress levels, derated components.	
		6.3	Output Gear Bearing Failure	Same as 6.2	Possible no start to secondary damage by misalignment and vibration		Same as 6.1	Bearing			Same as 6.1	Same as 6.2	

This analysis is also premature for determining dollar values; this can be accomplished in a demonstrator phase. The simplicity of the design, and the low cost of parts will definitely affect spares costs and repair material costs in a positive manner. The sparing strategy for the low cost, die cast, axial compressor rotors is a case in point. The low cost of the material is additive to the setup and machining time. The setup and machining time is cost sensitive to the quantity to be run, over which the machining costs are amortized. During the demonstrator phase of the program, we can realize the cost impact, derive actual cost values and thereby recommend optimum sparing levels.

SECTION IV

COST ANALYSIS

APPROACH

The jet fuel starter has been subjected to a cost analysis based on an established Design-to-Cost procedure. The method selected is based on: (1) identifying the "finite elements" of engine cost, at the part design level; (2) providing the designer with "real time" knowledge of the cost consequence of his design decisions; and (3) providing management visibility of on-going success in achieving cost targets.

Other constraints and considerations addressed in the development of this method are:

1. It must provide sufficient detail to be useful for the appropriate phase of design.

2. The method should be compatible with manual as well as data processing compilation procedures.

3. The approach must provide the manufacturing engineering activity with sufficient information to critique the design intent and contribute to achieving the cost objective.

The approach utilizes the cost-tree procedure to allocate initial cost objectives and commitments to engine groups, parts, and controls/accessories. A typical cost-tree for a hypothetical engine is shown on Figure 21.

During the design process, the cost of manufacturing (or acquiring) each part is compiled by finite elements. The elements include the man-hours for individual manufacturing operations, the material costs and the support costs (in man-hours and material) of inspection, tool support and certain overhead Operations. Man-hour and material costs are entered as "burdened" values and performance indices and anticipated scrap rates are included for each operation, or summarized for each part.

The finite element work sheet also provides for a progressive identification of the cumulative value of the part by summing each operation's "added value". This data aids in determinations such as: when to inspect; when to stop advance production (to minimize inventory cost); and (in actual production) the optimum decision for Materiel Review Board and scrap actions.

These medhods facilitate evaluating the cost consequence of changes in design and/or manufacturing operations. It also allows for estimating or specifying cost objectives as a function of production quantities and delivery rates. Burdened rates are used for material and labor but the burden (overhead and material handling costs) may vary as a function of the production quantity being estimated. However, all values are still in terms of cost and not price (i.e.,

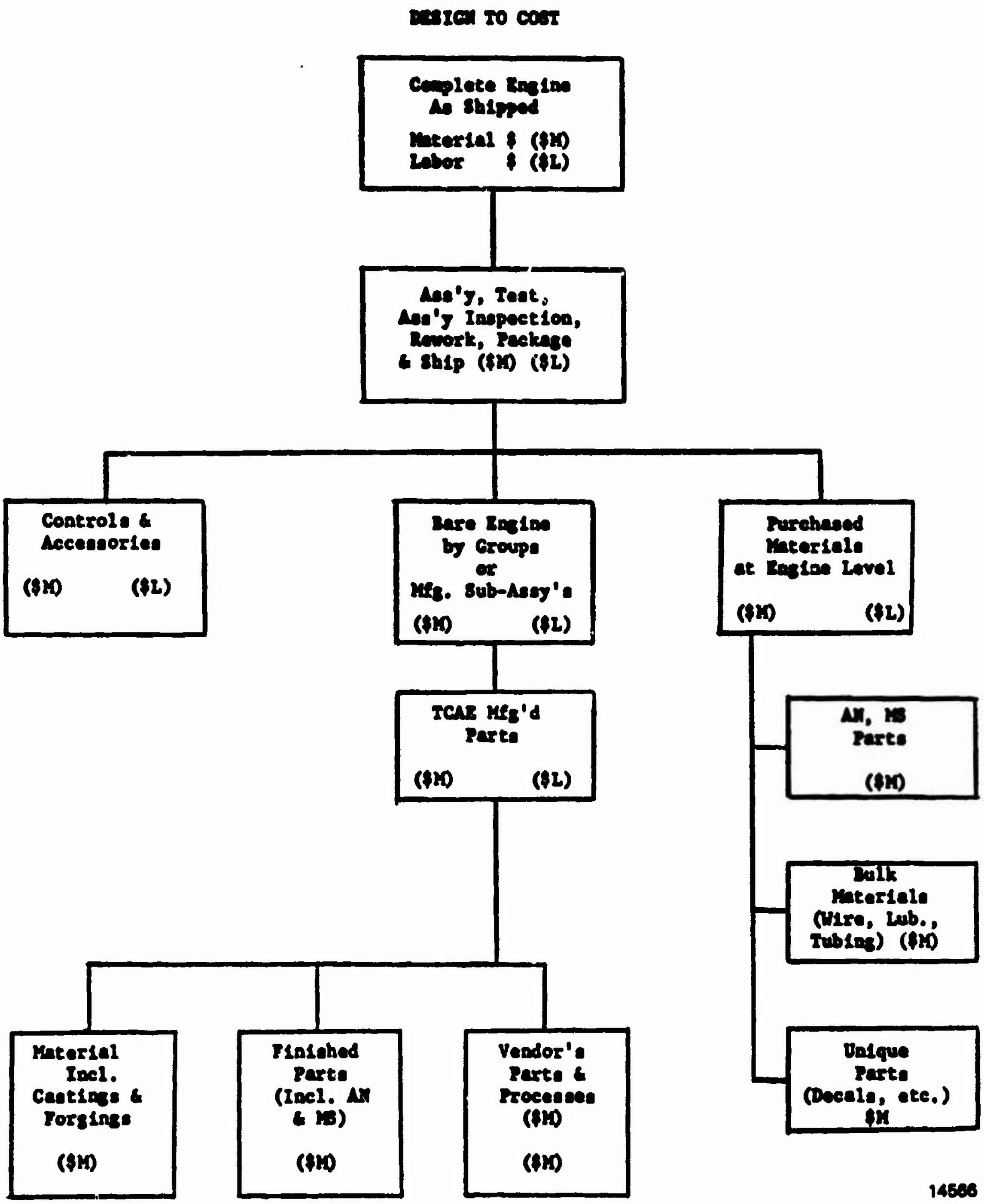

Figure 21. Engine Cost Tree.

they do not include G & A or Fee).

The cost of producing the specific parts of an engine are periodically compiled (by manual or data processing methods) into cost summaries for engine groups and for the total engine. This cost summary is then evaluated with respect to the initial cost objectives and commitments and also serves as an iterative cost model for the engine model of interest.

All values have been purposely retained in terms of cost to permit the designer to recognize the impact of his decisions towards achieving the cost targets. It is simply a matter of including G & A and Fee for the total engine cost to present the total selling price.

COST

To determine the cost to the customer of the JFS206 jet fuel starter, an abbreviated version of the detailed analysis described in the previous section was applied to all components of the engine. The results of the analysis are summarized for the major components of the JFS206 in Table 5. Experience has shown that preliminary cost of the components can be determined by a simplified approach which applies factors to both the standard labor hours and material dollars to arrive at total cost. This procedure uses the detail costing sheets filled out sufficiently to provide standard labor hours and material dollars for each component. These results are shown in standard labor hours and material dollars since each is treated differently in arriving at the selling price. The standard labor hours require additional labor hours for assembly, test and support functions and can be applied as a factor of 3.35 times the standard labor hours. This factor to estimate the supporting labor hours required is based on recent history of production engines, as these hours are representative to the effort required to support the direct machining and fabrication operations in the manufacturing of a gas turbine engine. The conversion of these labor hours to a selling price is accomplished by adding to the labor rate all burdens such as overhead, G&A, and profit to arrive at a selling price of $23.59 per labor hour. The material dollars for purchased parts and material is handled at a different rate. The total burden for material includes material overhead, G&A, and profit and can be applied as a factor of 1.46 times the material dollars.

Using the factors described and the data summarized in Table 5, the JFS206 price is as follows:

Labor Hours	- 22.9 x 3.35 x $23.59	= $1810
Material Dollars	- $2404 x 1.46	= $3510
Basic Engine		= $5320
Tooling and R&D Amoritzed over 2500 Units.		= $2021
	Total Estimated Price	= $7341

The budgetary unit production price includes Production Tooling and R&D amortized over 2500 units as established for this study and is based on FY1974 economics.

TABLE 5

LABOR AND MATERIAL FOR JFS206

PART NUMBER	PART OR OPERATION	MATERIAL	MANUFACTURING METHOD	STANDARD LABOR HOURS	MATERIAL DOLLARS
719580-1) " -3) " -5) " -7) 719652)	Four Compressor Rotor Stages	SC84A Aluminum	Die Casting	0.259	9.24
719580-4) " -6) " -8)	Four Compressor Stator Stages	SC84A Aluminum	Die Casting	0.256	9.24
" -9	Spacer, Compressor	Greek Ascoloy	Machined Tubing	0.263	4.84
719655	Nozzle, HP Turbine	MAR-M-509	Investment Casting	0.461	225.00
719653	Rotor, HP Turbine	IN-100	Investmant Casting	0.237	175.00
719656	Nozzle, Power Turbine	Stellite 31	Investment Casting	0.595	250.00
719654	Rotor, Power Turbine	INCO 713LC	Investment Casting	0.239	190.00
719580-14	Ring, Turbine Containment	17-4 PH	Rolled & Welded Ring	0.589	61.00
719580-15	Shaft, L.P.	Greek Ascoloy	Machined Bar	1.267	10.88
719580-18	Shaft, H.P.	Greek Ascoloy	Machined Bar	1.400	10.48
719580-28	Combustor	N-155	Sheet Metal Weld-ment	5.233	14.66
719580-29	Casing, Outer	6061-T6 Aluminum	Rolled & Welded Sheet	0.547	23.00
719658	Cover, Combustor	SC84A Aluminum	Die Casting	0.378	3.13
719659	Housing, Thrust Bearing	SC84A Aluminum	Die Casting	0.533	3.18
719580-37	Shroud, Compressor Stator	SC84A Aluminum	Die Casting	0.295	3.10
719660	Cover, Gear Box	SC84A Aluminum	Die Casting	0.367	3.57
MGL-4013	Electric Starter Assembly	—	Purchased	-	44.16
719580-95	Fuel Control Assembly	—	Purchased	0.400	650.00
719580-71	Shaft Assembly, Power Take-off	—	Machined Forging	0.679	52.51
Miscellaneous:					
—	Bearings	—	—	-	310.00
—	Gears, Shafts, Clutch	—	—	3.761	177.87
—	Rings, Pins, Nuts, Bolts, Keys Seals & Remaining Hardware	—	—	5.142	173.20
TOTAL BASIC ENGINE				22.901	$2404.06

SECTION V

ALTERNATE DESIGNS

JFS206-A1 ENGINE DESIGN

The JFS206-A1, engine alternate approach (Figure 22) uses a single-stage centrifugal compressor driven by a radial in-flow turbine as the gas generator rotor, thereby reducing the number of compressor stages as compared to the baseline design of the JFS206. The same low-cost static features as the baseline design have been used wherever practical.

The gas generator is comprised of a centrifugal compressor and radial diffuser, a reverse flow annular combustor, a turbine inlet nozzle and a radial inflow turbine. The centrifugal compressor operates at 40 percent greater speed than the baseline axial and consequently has much higher stress levels. The power turbine rotor is similar to the baseline, except due to the increased speed of the compressor, the small hole permissible through the gas generator precludes a simple suspension of the power turbine drive train. As a consequence, the power turbine is independently supported on two bearings at the rear and drives through a full floating quill to the straddle mounted pinion gear at the front end. This approach requires two additional high speed bearings and a quill splined at either end to replace the simple shaft pinned to the baseline engine. The mounting of the thrust bearing in the hot zone will require oil lubrication since fuel cannot provide the required lubricity for a heavily loaded thrust bearing, with added complexity to the lube system. The lube system would require a waste oil system requiring additional pumps and short term replenishment of the expended oil or a contained circulating oil system that would accommodate the thrust bearing heat rejection, inasmuch as it could not be rejected to the high ambient temperature frames.

The centrifugal compressor, due to its operational stresses, precludes the use of a die cast rotor and therefore costs more than the four die cast rotors used in the axial compressor engine. Considerably more high temperature material is needed to shroud the radial in-flow turbine and make the interstage transition between the gas generator and the power turbine.

The cost analysis of the JFS206-A1 has been performed on the detail components as has been previously discussed in Section IV. Using the same parameters as set forth for the baseline, the price summary is as follows:

Labor Hours - 25.8 x 3.35 x $23.59	=	$2039
Material Dollars - $3186 x 1.46	=	$4652
Basic Engine	=	$6691
Tooling and R&D amortized over 2500 units	=	$2021
Total Estimated Price	=	$8712

JFS206-A2 ENGINE DESIGN

The JFS206-A2 alternate approach (Figure 23) uses a single-stage centrifugal

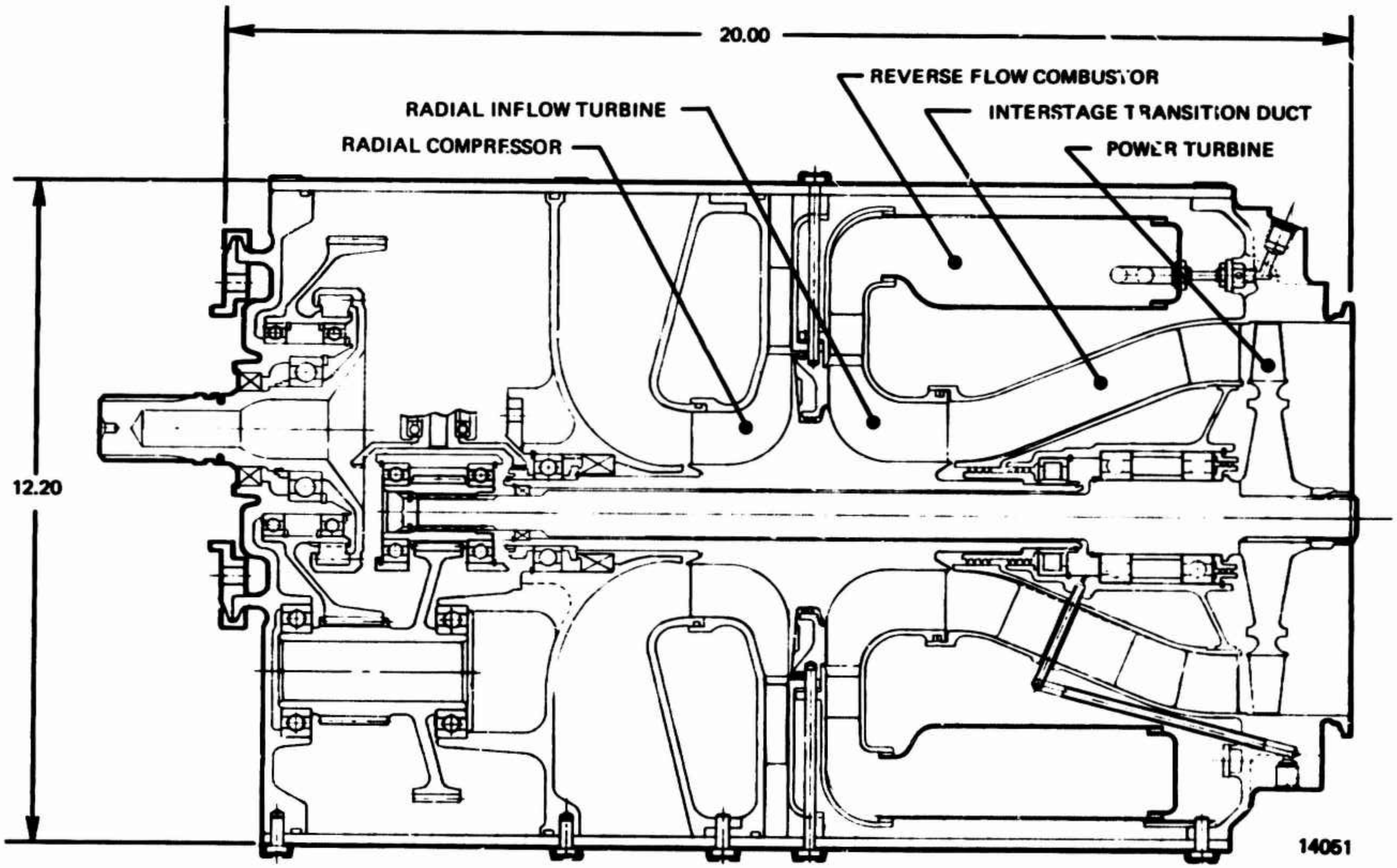

Figure 22. JFS206-A1 Jet Fuel Starter Alternate Design.

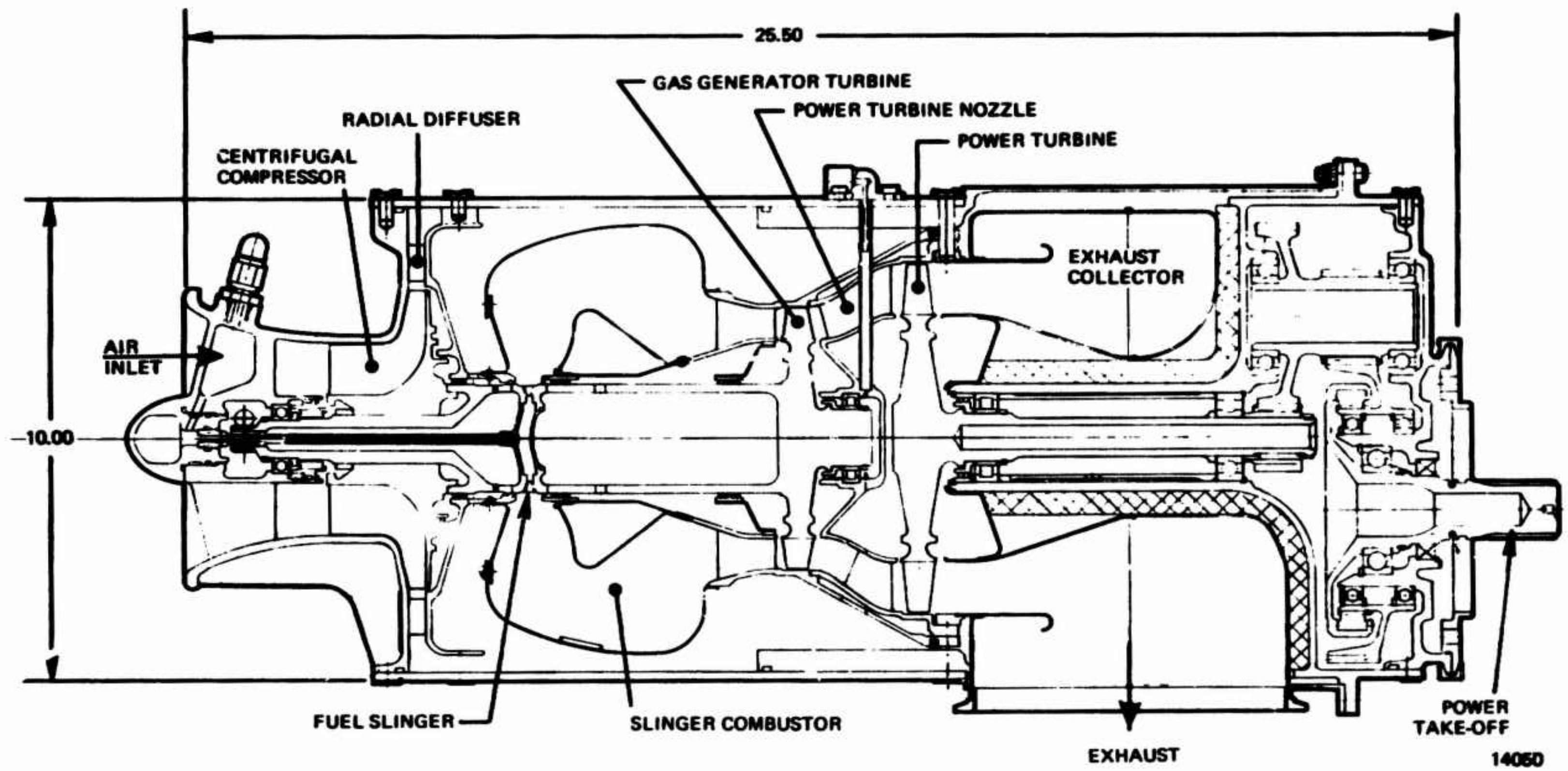

Figure 23. JFS206-A2 Jet Fuel Starter Alternate Design.

compressor driven by an axial turbine with rear power take-off and incorporates a slinger combustor to eliminate the problems associated with multiple injection in an annular combustor. The engine design uses a gas generator which is essentially the qualified (MQT) Teledyne CAE T-65 turboshaft engine, except for the removal of the supercharging axial compressor stage and replacing of the two-stage axial turbine with a single stage because of reduced work requirements. All detail design parts are modified to reflect the requirements for the Jet Fuel Starter (i.e., 2,000 starts at 45 seconds per start between overhauls). The design uses the low cost static structure features of the baseline design wherever practical.

The engine gas generator uses a single-stage centrifugal compressor and radial diffuser, a slinger combustor and an axial flow gas generator turbine. An axial-flow, free power turbine drives through a reduction gear and an overrunning clutch similar to the JFS206, except in this case the power takeoff is at the hot end of the engine and a concentric through-shaft is not used.

Air enters the centrifugal compressor, passes through a radial diffuser, then into an annular slinger combustor where fuel is added and combustion takes place. The hot gases pass successively through the gas generator turbine and power turbine, then enter the exhaust collector and exit at a right angle to the engine.

The fuel admission is through the center of the high speed rotating shaft and discharged through a row of holes in the shaft that makes up the fuel slinger. The injection velocity is derived from the tangential speed of the shaft and is thereby relatively insensitive to variations in fuel supply pressure.

The same high-speed compressor design as discussed for JFS206-A1 is used with the attendant fabrication cost due to the higher stress levels than the baseline design. An obvious added complexity with the non-through-shaft design is the complex, high temperature exhaust collector that must be provided to deflect the hot exhaust gases from the reduction gear. Additional complexities arise from bridging the exhaust collector with a cool structure and providing a large single outlet for the exhaust.

The cost analysis of the JFS206-A2 has been performed on the detail components as has been previously discussed in Section IV. Using the same parameters as set forth for the baseline, the price summary is as follows:

Labor Hours - 35.4 x 3.35 x $23.59	=	$2798
Material Dollars - $3503 x 1.46	=	$5114
Basic Engine	=	$7912
Tooling and R&D amortized over 2500 units	=	$2021
Total Estimated Price	=	$9933

COST AND PERFORMANCE COMPARISON

The alternate design approaches discussed under the previous two items have been presented to provide a comparison to the baseline design. The more conventional alternate designs use a higher pressure ratio of 3.9 and lower airflow of 1.95 pounds per second to achieve 148 shaft horsepower, which is very close to the 150 shaft horsepower of the baseline engine. The brake specific fuel consumption for the alternate designs is 1.08 lbs/bhphr versus 1.30 lbs/bhphr for the baseline design. The result of this trade-off has been to sacrifice specific fuel consumption for the lower pressure ratio to provide the low speed, lightly loaded JFS206. The design point data for the baseline and alternate designs have been included in Appendix C for complete performance comparisions.

The novel packaging of the JFS206 baseline engine provides both weight and volume advantages in addition to offering a cost advantage over both the JFS206-A1 and JFS206-A2. The volume advantages are shown in Figures 24 and 25 where the outline of the alternate designs are compared to the JFS206. The weight and cost advantages of the baseline engine are as follows:

MODEL	WEIGHT (lbs)	% WEIGHT INCREASE	COST ($)	% COST INCREASE
JFS206	98	-	7341	-
JFS206-A1	120	+ 22.4	8712	+ 18.7
JFS206-A2	125	+ 27.5	9933	+ 35.3

ALTERNATE TURBINE ROTOR CONSTRUCTION

The component parts of the JFS206 were thoroughly investigated during the preliminary design phase of this program. The parts were investigated to provide the minimum cost components to meet the requirements of the jet fuel starter. The present configuration of the JFS206 allows for disassembly of the hot-end components from the aft end for ease of disassembly and replacement. During the development of the hardware, the reliability and life of the hot end components can be determined, and it is conceivable that disassembly from the aft end may not be a requirement.

A further cost savings can be realized by using an alternate construction for both the gas generator turbine rotor (Figure 26) and the power turbine rotor (Figure 27). The gas generator turbine rotor is no longer piloted on and axially pinned to the shaft to transmit torque. This is accomplished by the same method of radially pinning the rotor to center it and to transmit the torque as is used for the compressor rotor. This design also eliminates the nut, locking ring, threads, and slots on the shaft.

The power turbine rotor alternate construction is press-fitted in the shaft and pinned at assembly. This design eliminates the key, key way, threaded shaft, and self-locking nut of the baseline design. In addition, the power turbine rotor becomes a solid disc which allows a thinner disc (less weight) to be used with the same margin of safety.

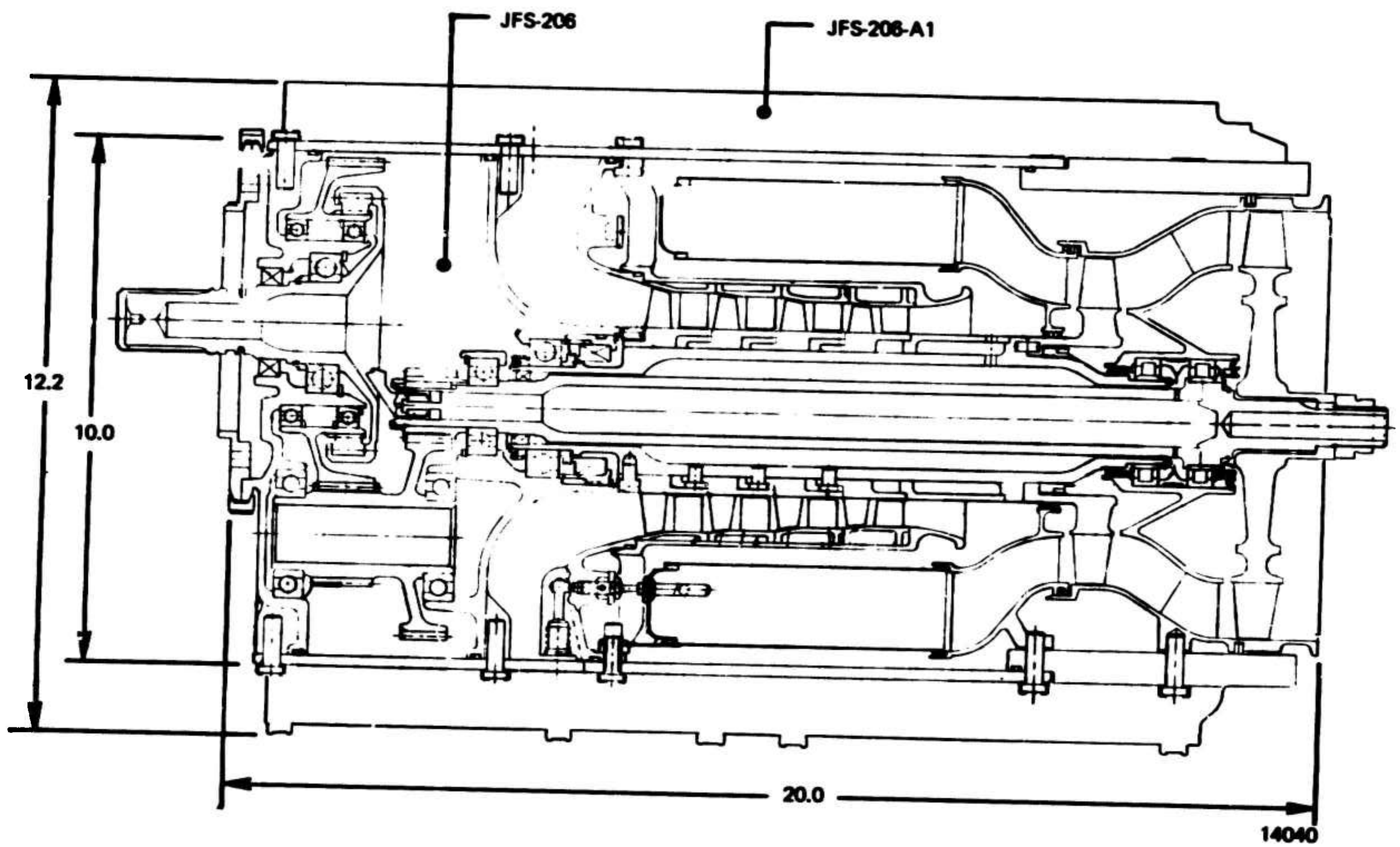

Figure 24. Comparison of JFS206 Baseline with JFS206-A1 Alternate.

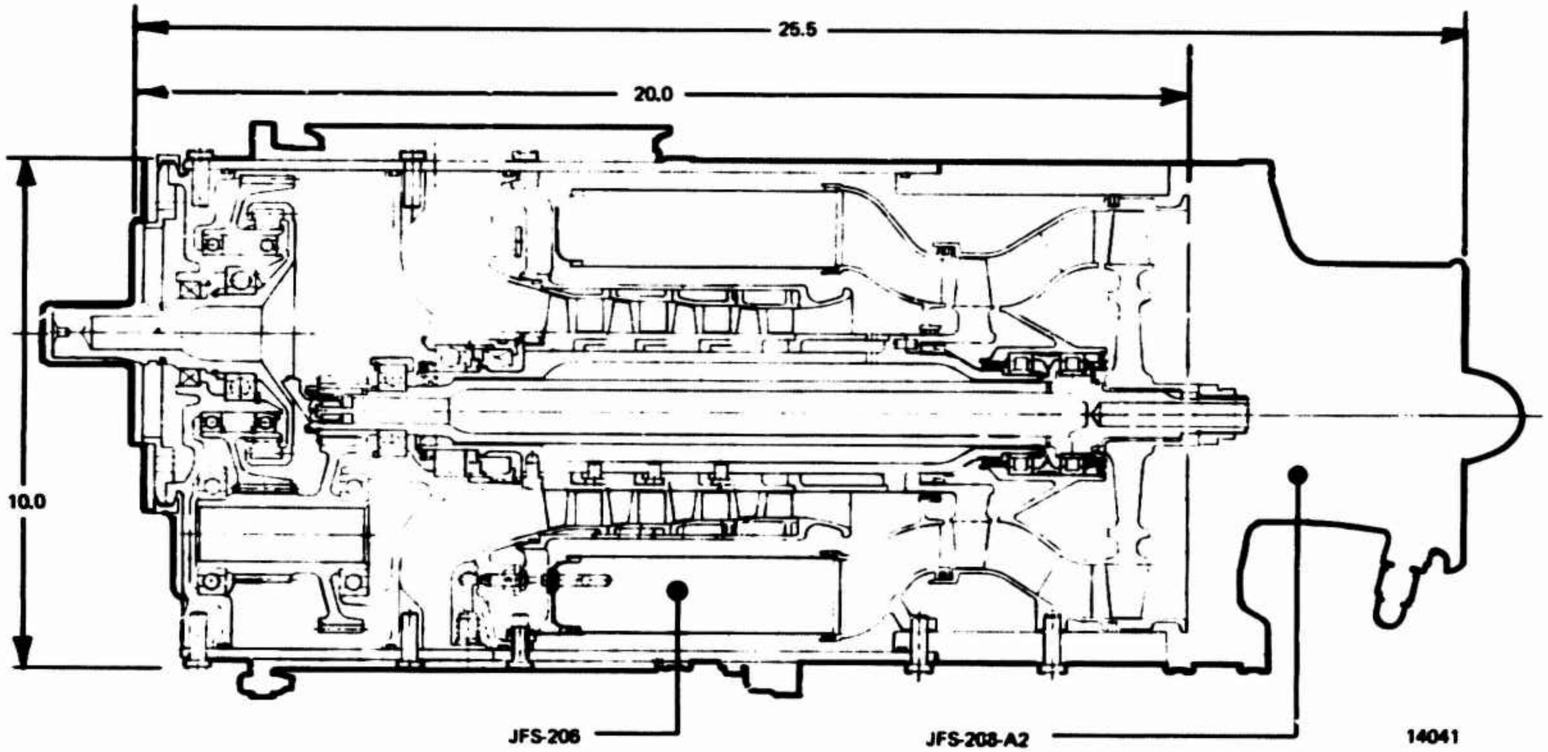

Figure 25. Comparison of JFS206 Baseline with JFS206-A2 Alternate Design.

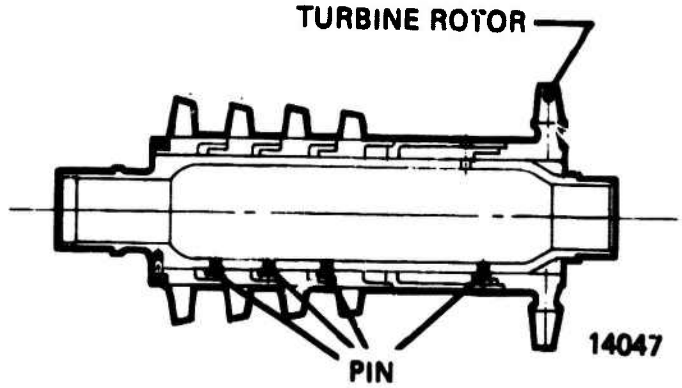

Figure 26. JFS206 Alternate Gas Genrator Turbine Rotor Construction.

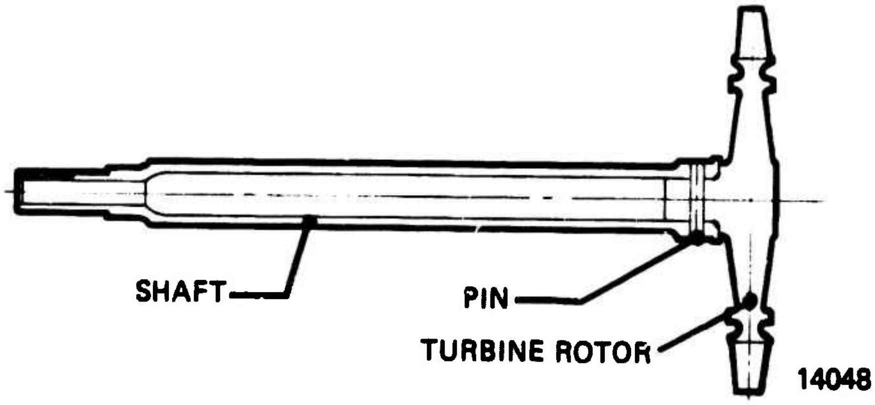

Figure 27. JFS206 Alternate Power Turbine Rotor and Shaft Construction.

The cost differential for the two alternate rotor constructions compared to the baseline rotors provides material dollars savings of $31.00 and standard labor hour savings of 0.557. When the price differential is applied to the baseline JFS206, it amounts to a savings of 1.2 percent. When it is applied to the turbine rotors and shafts involved, the difference becomes 10.7 percent which is considerable on a component basis.

DIRECT-DRIVE STARTER

The adaptation of the jet fuel starter to current engine designs requires a reduction gear to match the desired speed range. The use of a low speed power turbine eases the gearing problem by lowering the required reduction ratio. For new or future applications, a direct-drive starter could be integrated directly into the main engine gearcase or into a remote accessory box, thereby yielding an overall net savings in cost and weight. Two different starter designs are possible, one where the starter lubrication system is partially integrated with the accessory case, and the second where the starter lubrication system is totally independent.

INTEGRATED LUBRICATION SYSTEM

The direct-drive starter with integrated lubrication system is shown in Figure 28. The starter is 10 inches in diameter, 17.5 inches long and weighs 85 pounds. The power takeoff is integral with the power turbine and the overrunning clutch would be part of the main gearbox design. A magnetic speed pickup would sense the power turbine shaft speed and provide for safe and satisfactory operation of the starter control system as previously discussed. The fuel pump and starter fuel control would be repositioned from the initial design thereby permitting the short (17.5 inch) length. Lubrication of the thrust bearings and the fuel pump drive would be provided by the main engine gearbox. In the event of a "wet sump" system where an oil level to the centerline of the starter could be provided, a simple splash lube would be adequate. For a dry sump accessory case, the normal accessory lube system would be required to provide an oil jet feed to the thrust bearings, and an oil jet feed to the center of the tower shaft would lube the fuel pump drive train. A waste fuel system would still be used for the rear bearings. The lube flow would be provided by an external line as shown in Figure 29. The fuel air mixer tube would attach to the outer casing and fit into the bearing cavity with a slip fit to permit relative radial expansion of the hot and cold parts. The axial location is in line with the radial pins supporting the power turbine nozzle thereby eliminating axial differential thermal growths. The integrated lube system eliminates requirements for maintenance of a separate starter lube supply. The power output characteristics of the jet fuel starter are shown in Figure 30.

SELF-CONTAINED LUBRICATION SYSTEM

The direct-drive starter with a self-contained lubrication system is shown in Figure 31. A simple seal diaphragm and shaft seal are provided to retain the pot lube system for the thrust bearings and fuel pump drive system. The rear bearing lube system as used for the integrated system is retained. The added seal diaphragm and shaft seal will add 1.4 pounds to the starter weight for a total of 86.4 pounds.

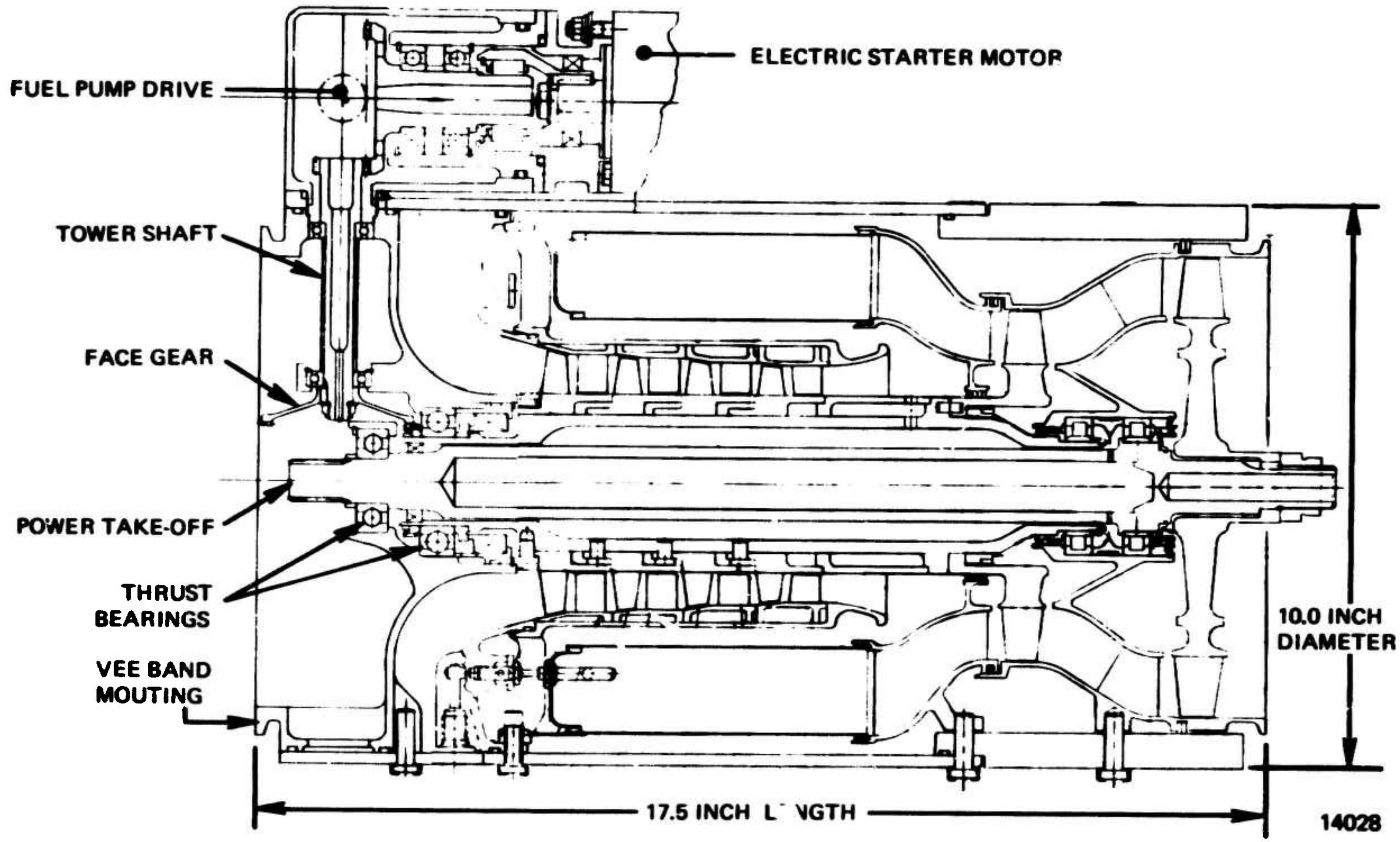

Figure 28. Direct-Drive Starter with Integrated Lube System.

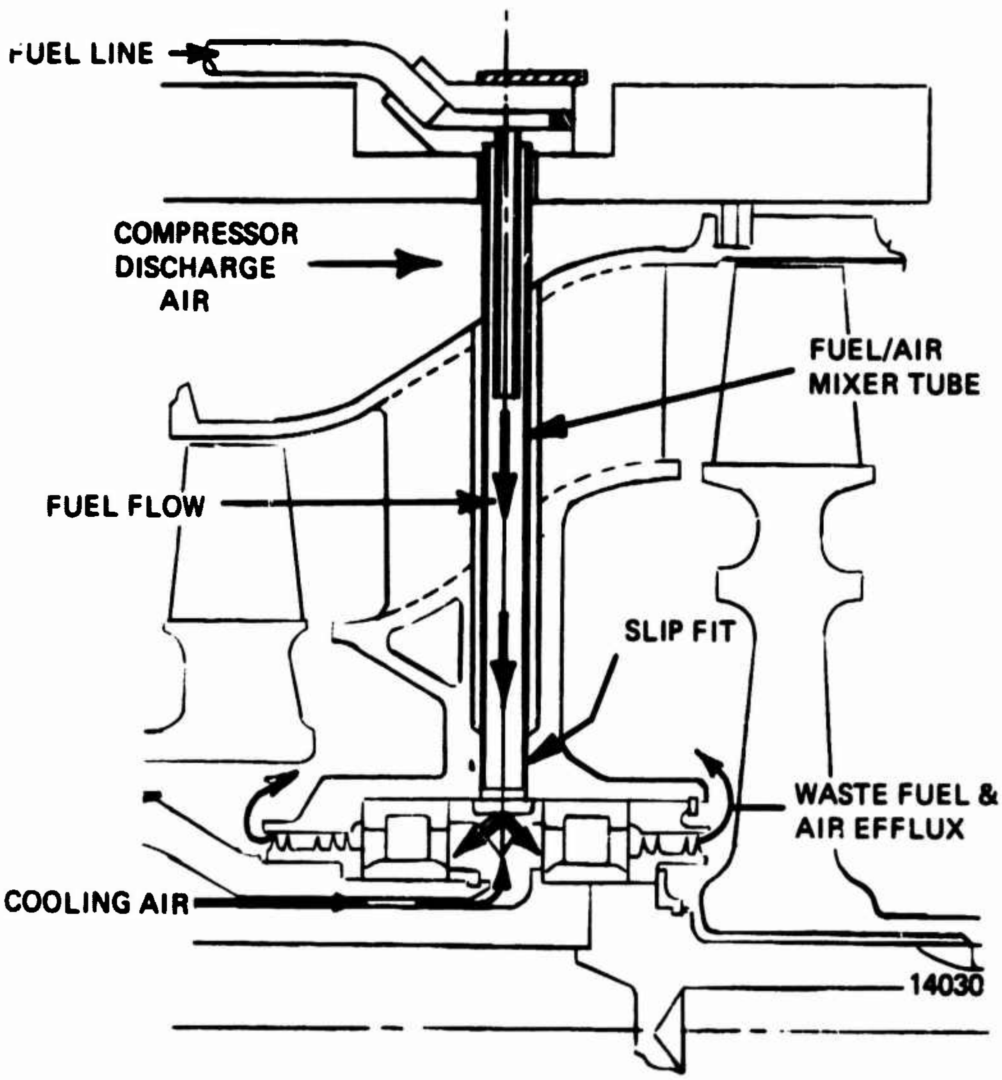

Figure 29. External Fuel Supply to Rear Bearings.

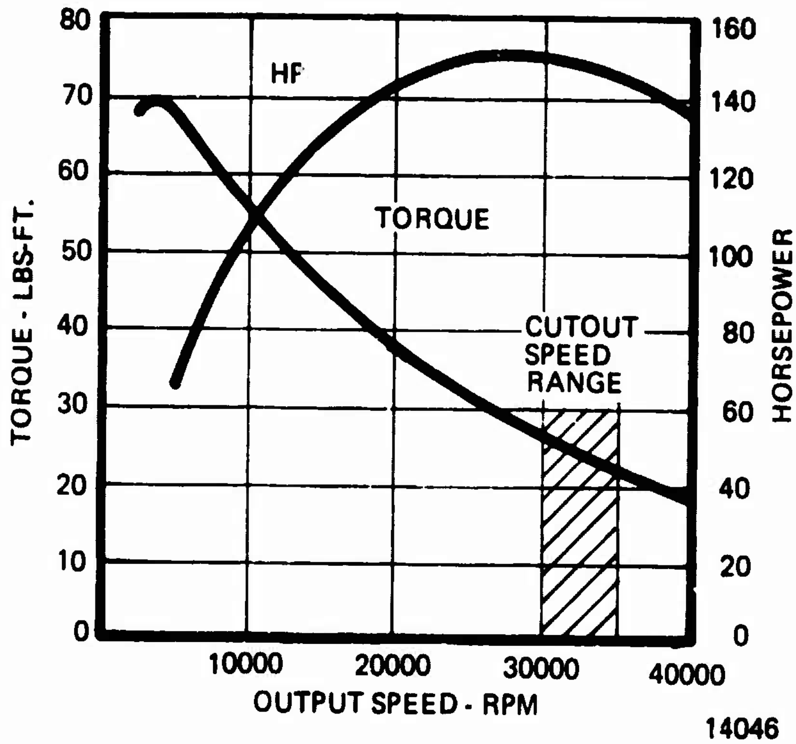

Figure 30. Direct Drive Starter Torque and Horsepower Characteristics.

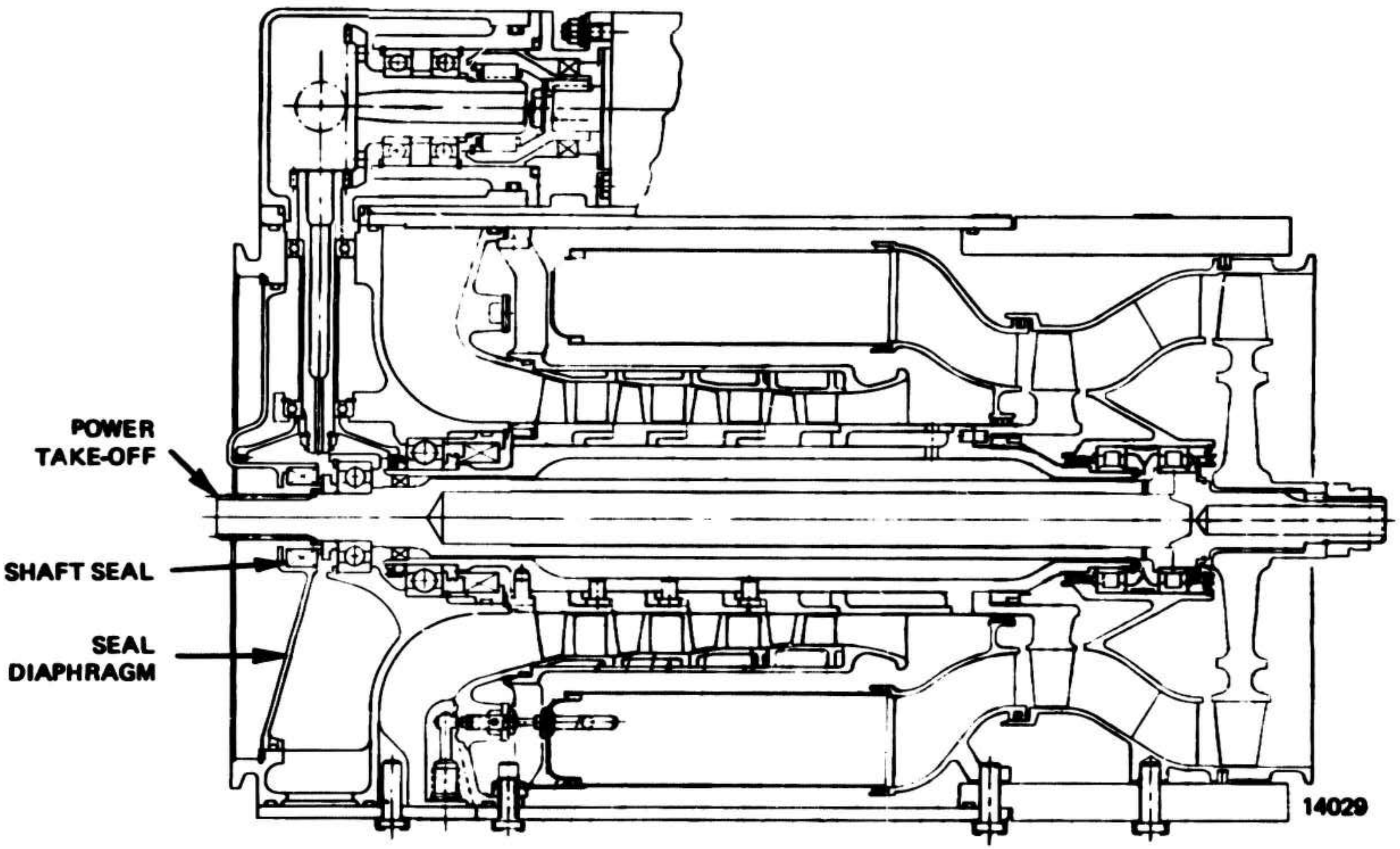

Figure 31. Direct-Drive Starter with Self-Contained Lubrication System.

SECTION VI

GROWTH POTENTIAL

COMPONENT IMPROVEMENTS

The JFS206 Jet Fuel Starter has significant growth potential (Table 6) built into its basic design without violating the exterior physical dimensions. Realization of the growth can be accomplished by improving component efficiencies and reducing total pressure losses in the flowpath.

To increase power output from the basic 150 horsepower to 186 horsepower, a 24 percent increase, requires improving compressor, gas generator turbine, and power turbine efficiencies one percent, increasing engine airflow three percent, reducing total pressure losses, and increasing the turbine inlet temperature to 1900°F. Achievement of these component performance improvements, without changing the engine physical size, is very realistic because the basic engine is degraded below the present state of the art. Improvements in component performance of the growth engine are summarized in Table 7.

HIGH TEMPERATURE TURBINES

A further example of the growth potential of this starter is illustrated in Figure 32. By increasing the turbine inlet temperature of the growth engine from 1900°F to 2300°F, the output power of the starter, while maintaining the basic frame size, can be increased as follows:

1. Cooled Turbine Version: Increased 26 percent from 186 to 236 HP.

2. Ceramic Turbine Version: Increased 32 percent, from 186 to 247 HP.

Compared to the basic engine, these represent a 57 percent increase, from 150 to 236 horsepower; and a 64 percent increase, from 150 to 247 horsepower.

Current progress in the development of ceramic components at Teledyne CAE and throughout the turbine industry could lead to a low cost method of fabricating ceramic components for future growth engines.

TABLE 6

SEA LEVEL DESIGN POINT ENGINE PERFORMANCE COMPARISON

COMPONENT	BASIC ENGINE	GROWTH ENGINE
OVERALL PERFORMANCE:		
POWER TURBINE OUTPUT - HP.	180	188
BSFC - LBS/HR -BHP	1.30	1.16
AIRFLOW - LBS/SEC.	2.23	2.29
INLET CONDITIONS:		
AMBIENT TEMPERATURE - °F	[illegible].7	[illegible].7
AMBIENT PRESSURE - psia	14.7	14.7
INLET PRESSURE RECOVERY - %	[illegible].0	[illegible].0
COMPRESSOR:		
PRESSURE RATIO	2.[illegible]:1	2.[illegible]:1
ADIABATIC EFFICIENCY - %	80.0	81.0
GAS GENERATOR TURBINE:		
TURBINE INLET TEMPERATURE	1800	1900
ADIABATIC EFFICIENCY - %	82.5	83.5
POWER TURBINE:		
ADIABATIC EFFICIENCY - %	80.0	81.0
MECHANICAL EFFICIENCY - %	[illegible].0	[illegible].0
TOTAL PRESSURE LOSS - %		
COMBUSTOR	5.0	3.5
INNER TURBINE PASSAGE	1.5	1.0
EXHAUST DIFFUSER	5.0	4.0
SPEED - RPM		
GAS GENERATOR	43,[illegible]00	43,[illegible]00
POWER TURBINE	2[illegible],000	2[illegible],000

13[illegible]

TABLE 7

SEA LEVEL DESIGN POINT COMPONENT IMPROVEMENTS

COMPONENT	BASIC ENGINE	GROWTH ENGINE	CHANGE FROM BASIC ENGINE
COMPRESSOR:			
AIRFLOW - LBS/SEC.	2.23	2.29	+3%
ADIABATIC EFFICIENCY - %	80.0	81.0	+1.0 POINT
GAS GENERATOR TURBINE:			
TURBINE INLET TEMP. - °F	1800	1900	+100
ADIABATIC EFFICIENCY - %	82.5	83.5	+1.0POINT
POWER TURBINE:			
ADIABATIC EFFICIENCY - %	80.0	81.0	+1.0 POINT
TOTAL PRESSURE LOSS (%)			
COMBUSTOR	5.0	3.5	−1.5
INNER-TURBINE PASSAGE	1.5	1.0	−0.5
EXHAUST DIFFUSER	5.0	4.0	−1.0

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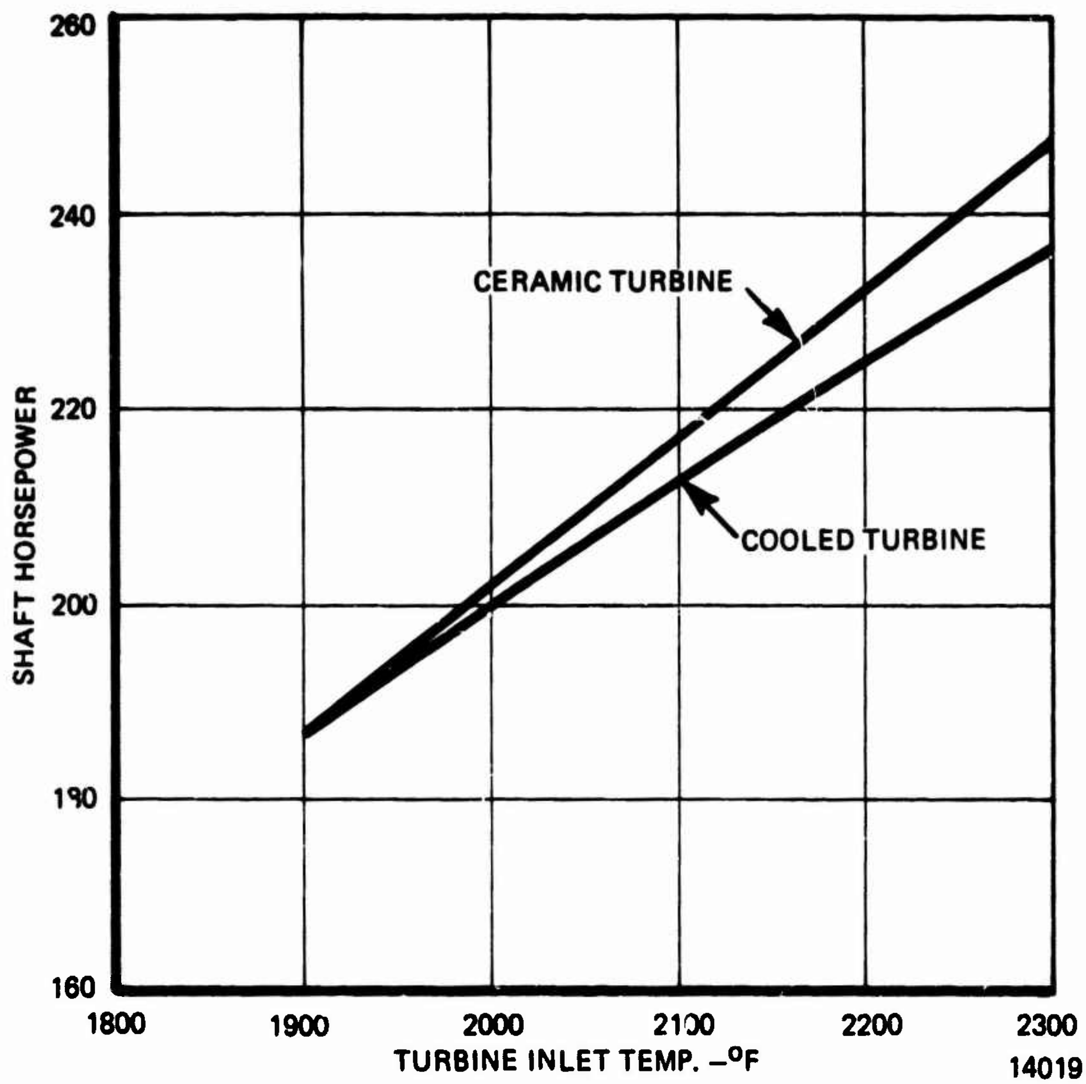

Figure 32. Effect of Increased Turbine Inlet Temperature on Engine Output Horsepower.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The preliminary starter design, as shown in Figure 33, can meet the objective of an $8000 unit selling price. The starter, designated as JFS206 Jet Fuel Starter, is 10 inches in diameter, 20 inches long, weighs 98 pounds and produces a maximum output of 150 horsepower. The starter is a two shaft engine with a radial air inlet and axial exhaust, a reduction gear, a fuel pump and control, and an electric starter motor. This lightweight, compact unit contains all the features necessary to perform safe and reliable starts of the main engine. The starter is capable of operating over an ambient temperature range of -65°F to 130°F and at altitudes up to 8,000 feet. It incorporates containment provisions to preclude damage to the aircraft in the unlikely event of rotor burst.

The design incorporates the following low cost features:

- Low Speed Rotor Design with Die Cast Aluminum Compressor Rotors
- Low Speed Rotor Design Permits a Concentric Shaft Design with Each Rotor Simply Supported on Two Bearings
- Concentric Shaft Design eliminates Expensive, Complex Exhaust Elbow
- Simple, Annular Vaporizer Combustor with only three fuel injection pipes and three "tee canes"
- Die Cast Aluminum Housings
- Simple, Cylindrical Rolled Aluminum Outer Casing
- Rolled Steel Containment Ring
- Radial Pin Joint Construction
- Electronic Fuel Control with Motor Driven Metering Pump and Engine Driven Centrifugal Pump
- Commercially Available Outboard Engine Electric Starter
- Pot Lube Reduction Gear and Thrust Bearings
- Waste Fuel Lube Rear Bearings
- Face Gears in Accessory Drive
- Minimal Use of Expensive High Temperature Materials

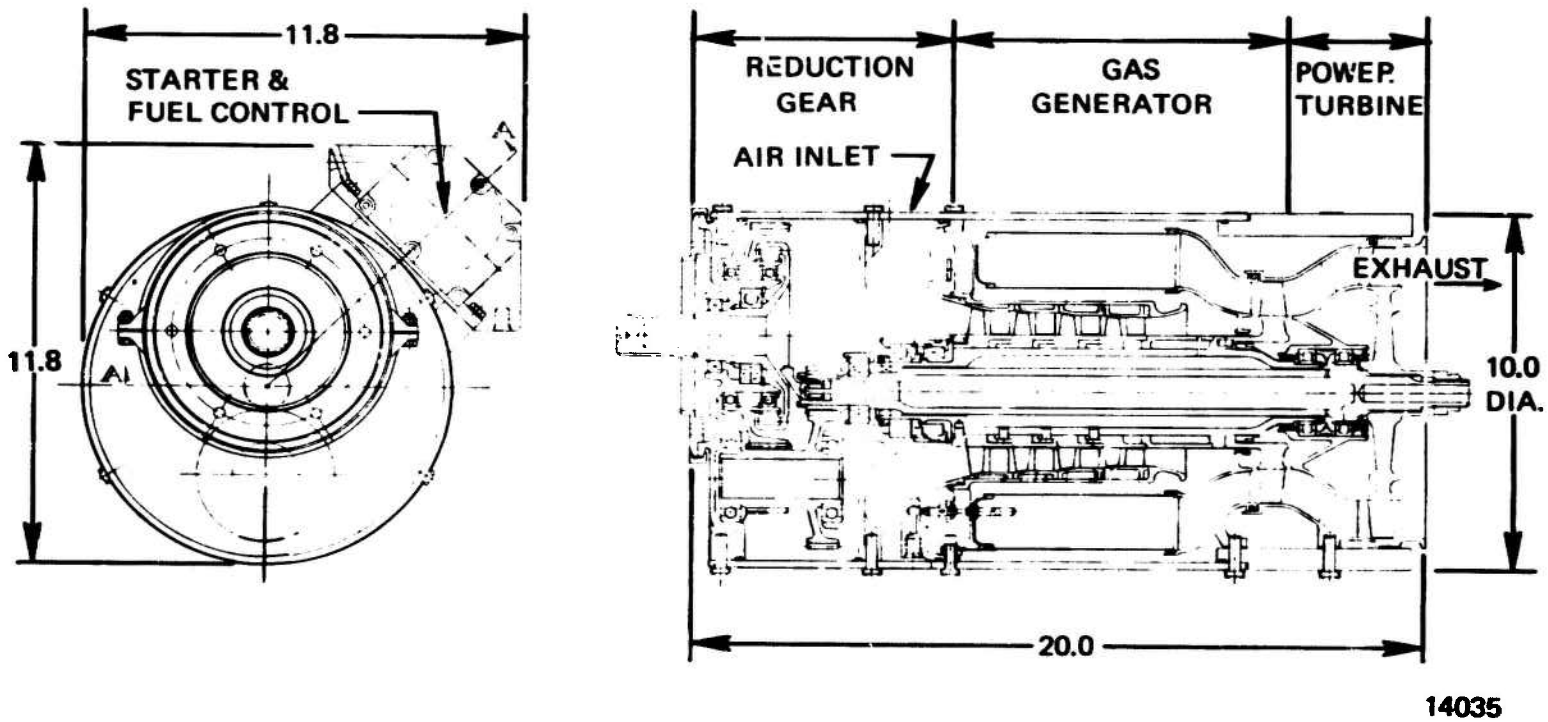

Figure 33. JFS206 Jet Fuel Starter.

- Maximum use of cast components to minimize Machining.

Two additional starter design approaches were prepared and compared to the JFS206 design to justify the basic design approach. A low speed concentric shaft engine design, although having more compressor rotors, permits a simple construction and low cost fabrication techniques with an overall reduction in total parts and total starter cost.

RECOMMENDATIONS

It is recommended that a full scale demonstration engine, (Task 8), incorporating all the starter systems, be built and tested to prove the validity of the low cost features of this study. To build logically to this objective, seven discrete component tasks have been identified. It is recommended that they be accomplished as a necessary part of the full scale demonstrator program.

Task 1: Combustor Rig Test

In return for low cost and volume, the compact, simple combustor design with only three fuel nozzles and three "T canes" represents the only high risk aerodynamic components. Consequently, a combustor rig test program should be initiated.

This rig testing of the combustor will provide operational definition and resolution of the following parameters:

1. Combustor Efficiency
2. Pressure Loss
3. Temperature Distribution Factor
4. Minimum Temperature Rise
5. Radial Temperature Gradient
6. Fuel Injector System Efficiency

Task 2: Gas Generator

A full scale gas generator should be designed, fabricated and tested to demonstrate satisfactory thermodynamic and mechanical operation. The gas generator testing will provide confirmation of the:

1. Air Flow
2. Compressor Pressure Ratio
3. Compressor Adiabatic Efficiency
4. Turbine Inlet Temperature
5. Turbine Adiabatic Efficiency
6. Combustor Pressure Losses

Task 3: Waste Fuel Lube System

A bearing test rig should be designed, fabricated and tested to demonstrate the waste fuel lube and air cooling of the rear roller bearings. The 25 hours of operation and 2000 starts required by the JFS206 can readily be demonstrated using this rig. The proper fuel flow rate will be determined during rig operation. The bearing test rig will be used to:

1. Determine the proper fuel lubrication flow to the bearing.

2. Determine the cooling air flow for the bearing.

3. Demonstrate the capability of the bearing and lube system to complete 2000 cycles of operation.

Task 4: Reduction Gearbox Rig Test

A back-to-back gearbox test rig should be designed, fabricated and tested to demonstrate the power transmission hardware and its lubrication system. The engine hardware, in order to meet the cost objectives, will use unground gears as received after heat treatment.

The Rig will be used to:

1. Evaluate the heat treated gear distortions under varying conditions of speed and torque, simulating actual points of engine operation.

2. Establish proper gearbox oil level.

3. Confirm operating capability at different altitudes.

4. Establish oil baffle design requirements (if needed).

Task 5: Die Cast Rotor

The die cast rotor requires the application of die casting techniques to an axial rotor fabrication. The revisions to the rotor design to permit successful die casting will be established during the rotor fabrication phase. The die cast rotors will be:

1. Subjected to spin pit testing to establish their structural integrity.

2. Vibration testing to establish blade frequencies and endurance limits.

3. Gas generator testing to establish aerodynamic performance.

Task 6: Preliminary Demonstrator

The preliminary demonstrator will provide an evaluation of the complete starter without the automatic control system. The following components will be added to the basic gas generator of Task 2:

- Reduction Gearbox
- Overrunning Clutch
- Front Housing
- Power Shaft
- Turbine Inlet Nozzle
- Power Turbine

Testing of the basic demonstrator engine will allow compiling of the following data:

1. Power Turbine Mechanical Efficiency.
2. Power Turbine Adiabatic Efficiency
3. Inter-Turbine Duct Losses.
4. Shaft Horsepower.

This data will verify the performance of the basic engine configuration.

Task 7: Control System

The design fabrication and bench testing of the complete control system will be conducted under this task. The control system will include the fuel pump and metering valve, electronic control speed sensors and the necessary valving and automatic sequencing system to provide a complete control system for the jet fuel starter. Bench testing of the control will establish the following:

1. Fuel pumping characteristics.
2. Metering pump capability.
3. Speed sensor operation.
4. Sequencing system.

Task 8: Fully Operational Demonstrator

The fully operational demonstrator engine will incorporate all the features and elements of the first seven tasks. This demonstrator will add the Control System (Task 7) and the die cast rotor (Task 5) components to the Preliminary Demonstrator (Task 6) to provide a complete starter with all critical low cost features. This unit will demonstrate the following:

1. Functional ability of the starter to perform safe starts.

2. Checkout of the automatic sequencing system.

3. Confirm engine output power.

4. Evaluate low cost structural features.

5. Confirm total package weight.

APPENDIX A

ASSEMBLY DRAWINGS AND BILL OF MATERIALS

The jet fuel starter design is defined by the assembly drawing and a bill of materials itemizing the total number of parts required. Figures A-1 through A-3 show the engine design, and Figure A-4 defines the bill of materials for the selected JFS206 starter.

The same data was prepared for the two alternate designs, JFS206 A-1 and JFS206 A-2 to provide a basis for detail cost estimates. These drawings and bill of materials are shown in Figures A-5 through A-10.

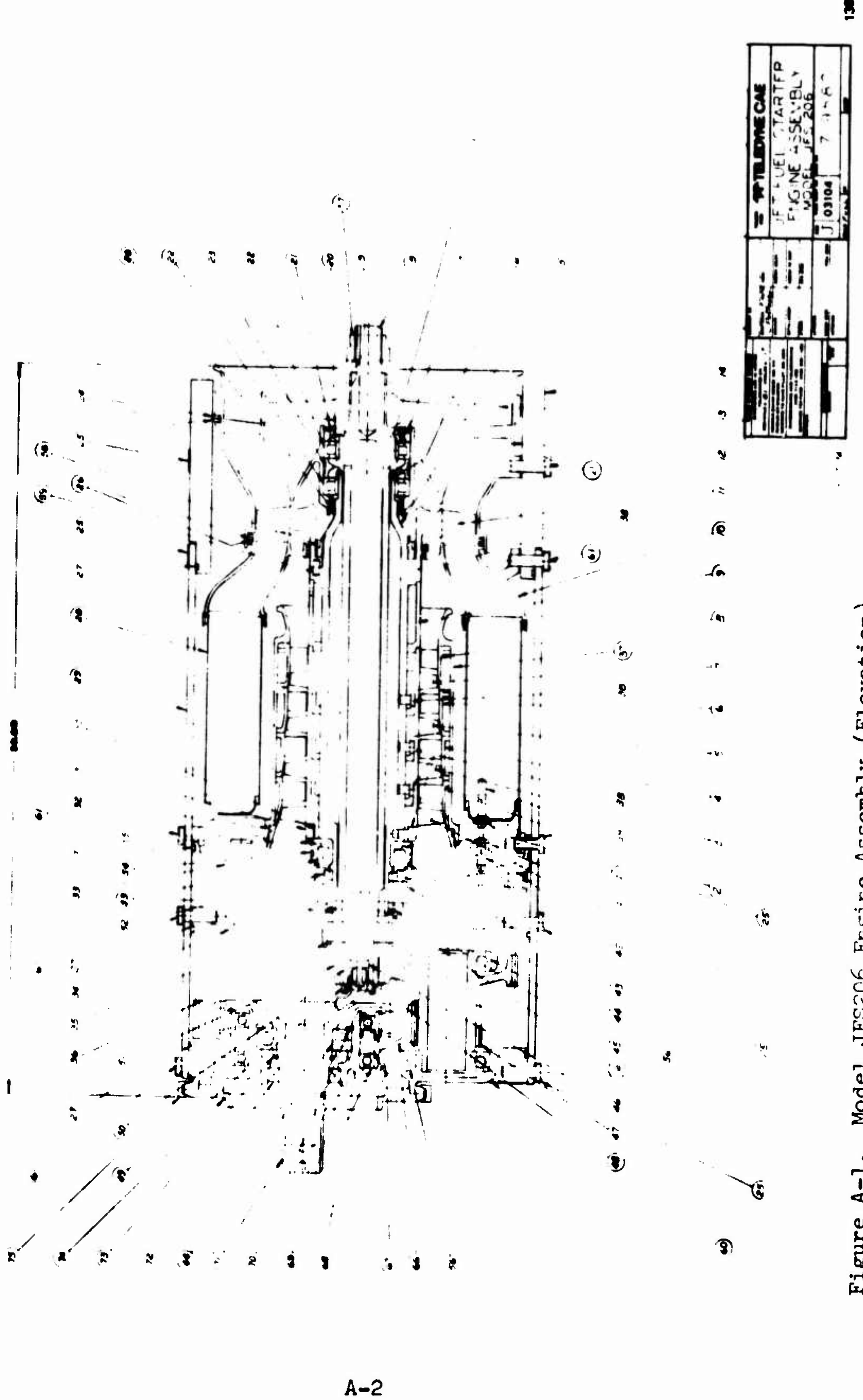

Figure A-1. Model JFS206 Engine Assembly (Elevation).

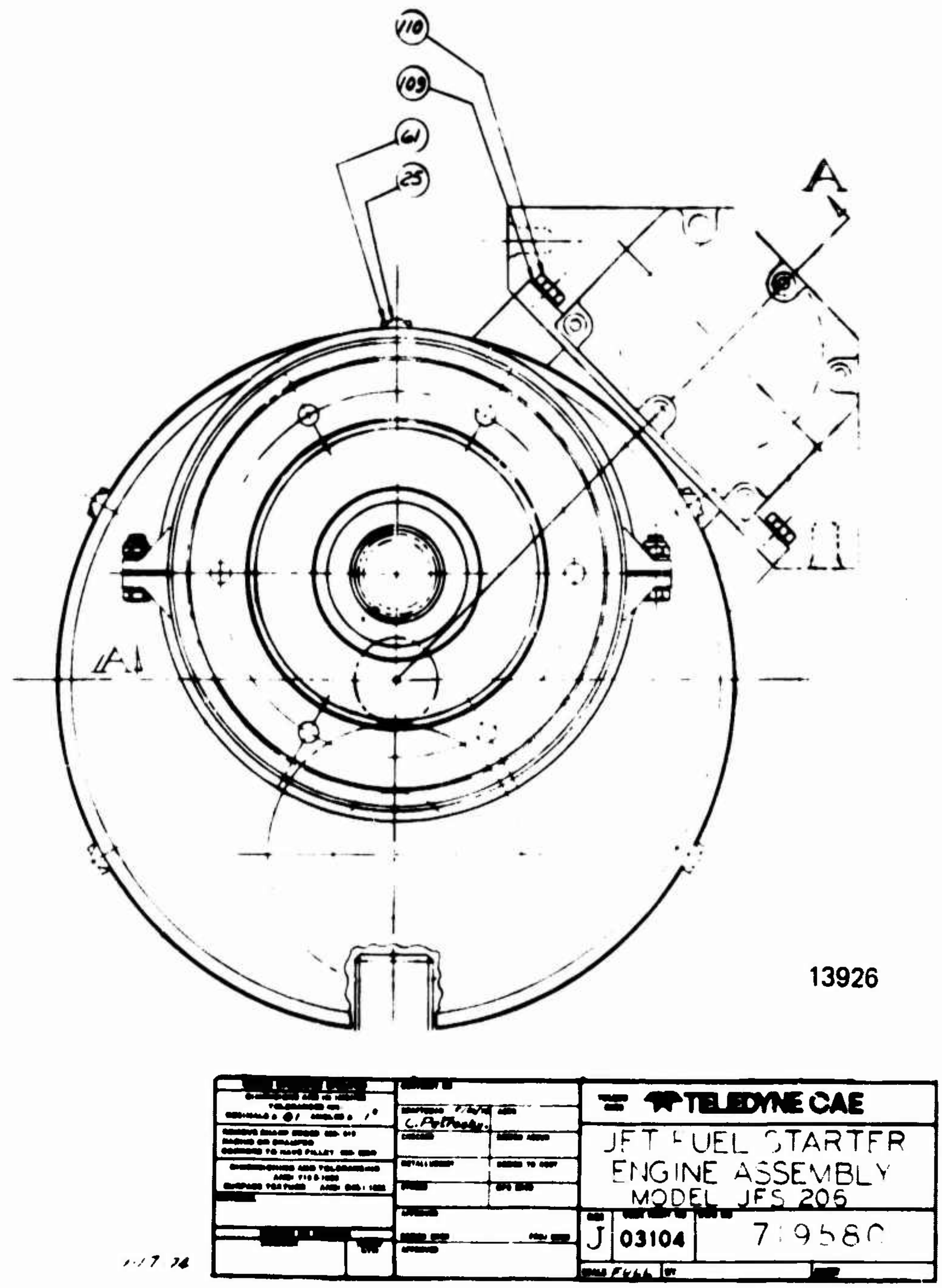

Figure A-2. Model 206 Engine Assembly (End View).

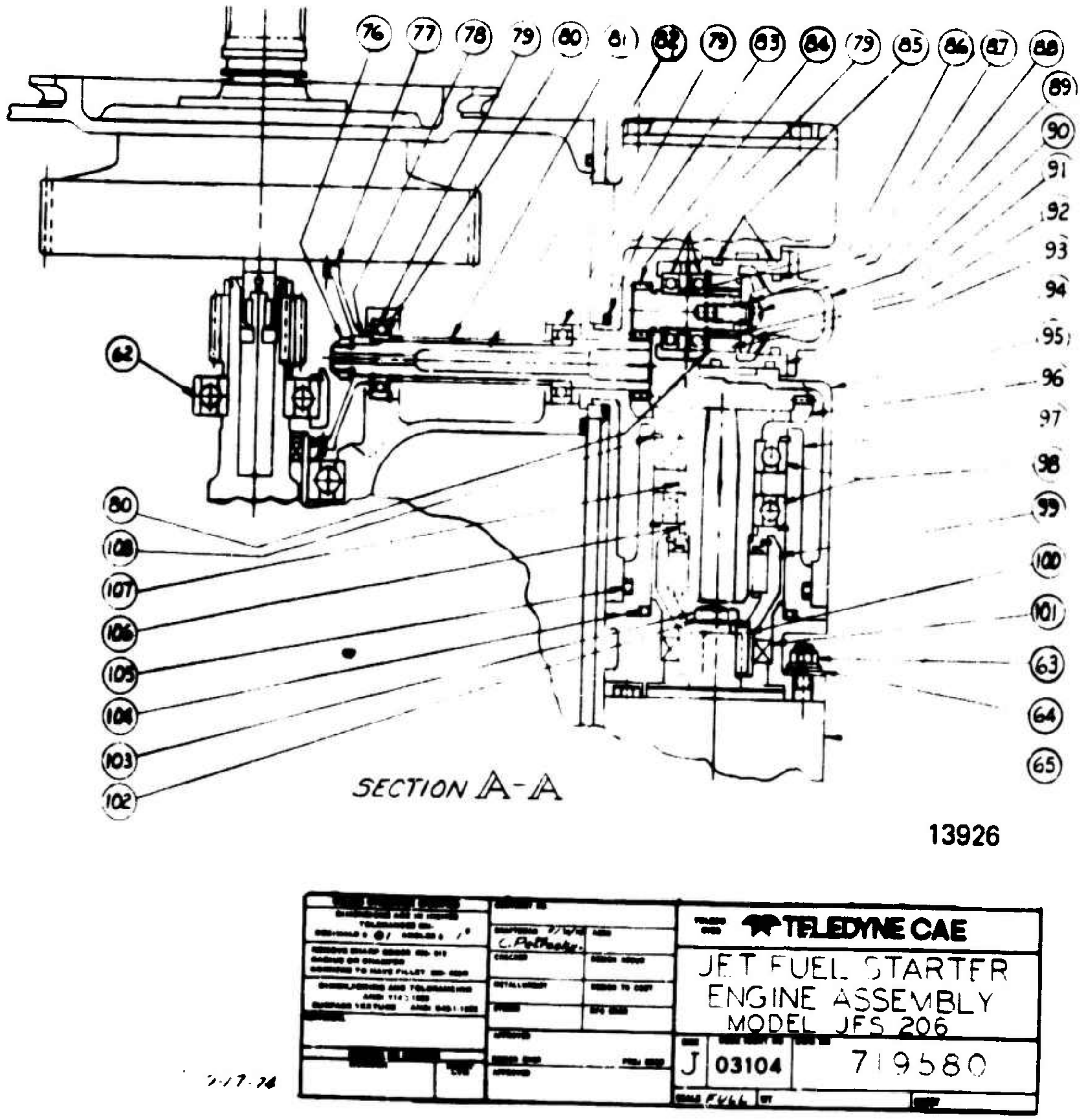

Figure A-3. Model 206 Engine Assembly (Section A-A).

QTY REQ'D PER ASSY	CODE IDENT NO	PART NUMBER	NOMENCLATURE OR DESCRIPTION	DRAWING NO OR DOCUMENT NO	ZONE	FIND NO
1		-111	RING		4	11
4		-110	BOLT		8	110
4		-109	WASHER		8	109
2		-108	RING		8	108
1		-107	SPACER		8	07
1		-106	RING		8	106
1		-105	"D" RING		8	105
1		-104	"O" RING		8	104
1		-103	BOLT		8	103
1		-102	WASHER		8	102
1		-101	SEAL		7	101
1		-100	KEY		7	100
1		99	CLUTCH ASSY		7	99
2		-98	BEARING		7	98
1		-97	HOUSING		7	97
1		-96	GEARSHAFT		7	96
1		-95	FUEL CONTROL ASSY		7	95
1		-94	HOUSING		7	94
1		-93	SEAL		7	93
1		-92	IMPELLER		7	92
1		-91	SPACER		7	91
1		-90	COVER		7	90
1		-89	SCREW		7	[illegible]
1		88	WASHER		7	88
1		87	D RING		7	87
		86	SPACER		7	86
2		-85	"O" RING		7	85
		-84	GEARSHAFT			84
1		83	"O" RING		7	83
		82	GEARSHAFT		8	82
		-81	SPACER		8	81
2		80	RING		8	80
4		79	BEARING		8	79
		-78	KEY		8	78
		77	GEAR		8	77
		76	NUT		8	76
		75	V BAND ASSY		6	75
		74	ADAPTOR		6	74
		-73	RING		6	73
		-72	SEAL		6	72
		71	SHAFT ASSY		6	71
		-70	RING		6	70
		69	RING		6	69
2		68	BEARING		6	68
2		67	RING		6	67
		66	GEAR		6	66
	[illegible]	[illegible]	[illegible] ASSY		7	65
		64	[illegible]		7	64
		[illegible]			7	63
		[illegible]	BEARING		5	62
		[illegible]	[illegible]		[illegible]	6

QTY REQ'D PER ASSY	CODE IDENT NO	PART NUMBER	NOMENCLATURE OR DESCRIPTION	DRAWING NO OR DOCUMENT NO	ZONE	FIND NO
1		[illegible]	COVER		6	60
		-59	PIN		5	59
1		-58	NUT		4	58
		-57	[illegible]		4	57
2		56	BEARING		6	56
1		-55	RING		5	55
		54	"O" RING		5	54
		-53	SEAL		6	53
		52	[illegible]		6	52
1		5[illegible]	GEAR		6	5[illegible]
		50	KEY		6	50
1		-49	RING		6	49
1		-48	SEAL		6	48
1		-47	GEAR		6	47
		-46	[illegible]		6	46
1		45	GEAR		6	45
2		-44	BEARING		6	44
		43	LINER		6	43
3		-42	BOLT		6	42
		-4[illegible]	COVER		6	4[illegible]
3		40	NUT		5	40
3		[illegible]	[illegible] VANE		5	39
[illegible]		-38	[illegible]		5	38
		37	SHROUD		5	37
		-36	RING		6	36
		35	SEAL		6	35
		[illegible]	HOUSING		6	[illegible]
		[illegible]	[illegible]		6	[illegible]
		[illegible]	O RING		5	32
		3[illegible]	RING		5	3[illegible]
		30	RING		5	30
		-29	CASING		5	29
		28	COMBUSTOR		5	28
4		27	C RING		56	27
		-26	PISTON RING		6	26
		25	RING		46	25
2		[illegible]	PISTON RING		4	24
		23	SPLITTER		4	23
2		22	BEARING		4	22
		2[illegible]	SPACER		4	2[illegible]
		[illegible]	SEAL		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		4	[illegible]
		[illegible]	[illegible]		5	[illegible]
		[illegible]	[illegible]		[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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Figure A-4. Model 206 Engine Assembly (Bill of Materials).

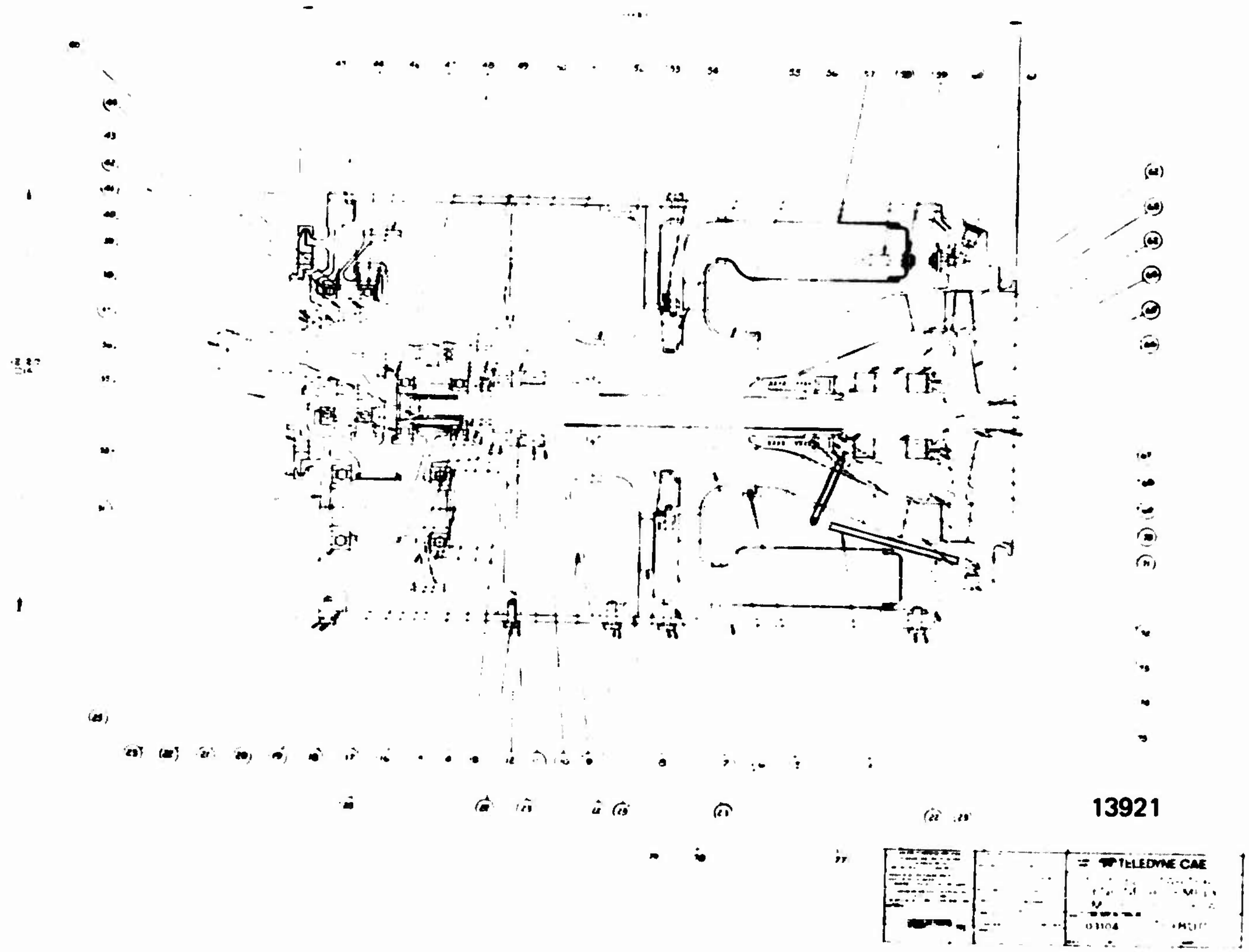

Figure A-5. Model JFS206 A-1 Engine Assembly (Elevation).

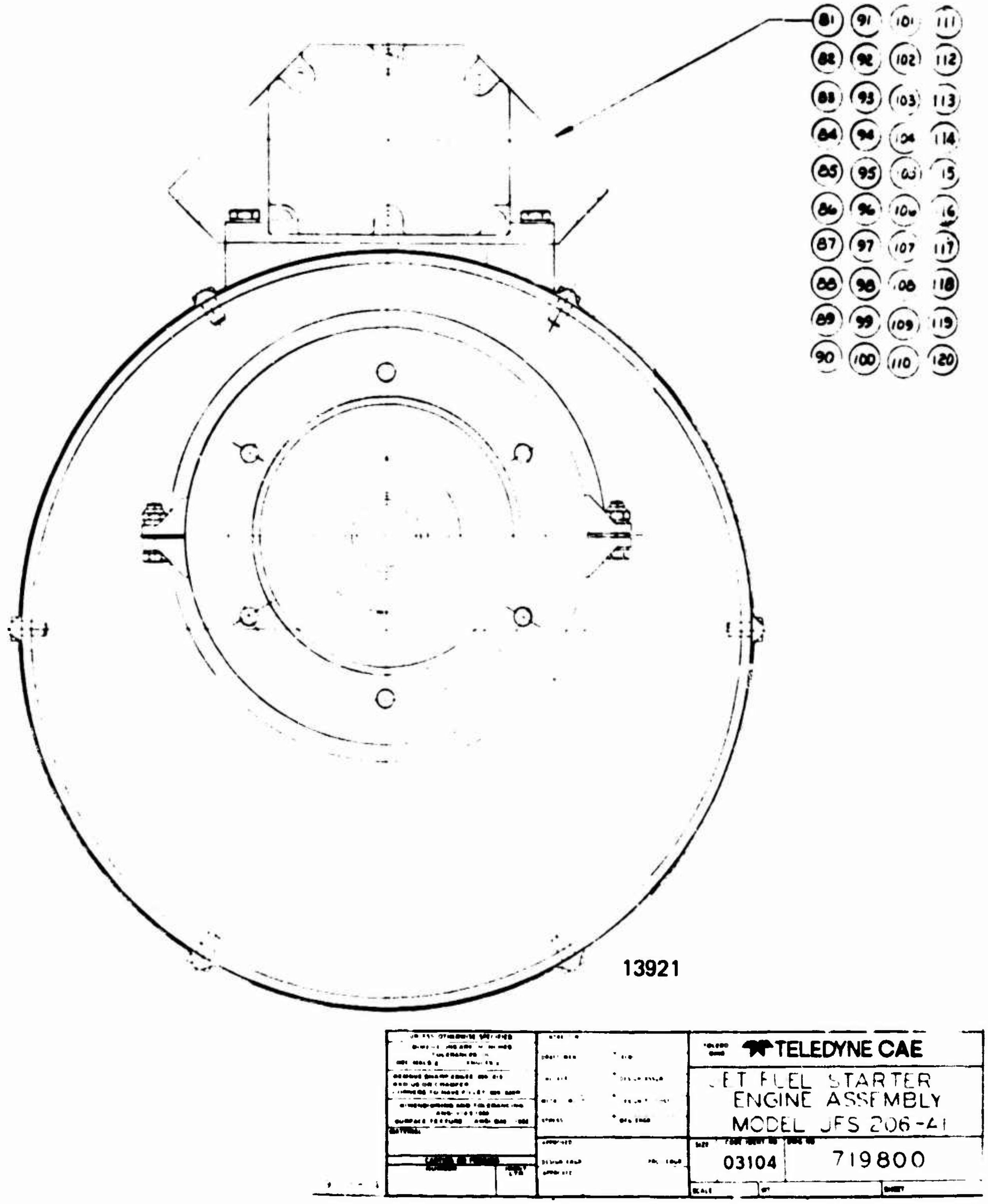

Figure A-6. Model [illegible] Engine Assembly (End View).

QTY REQ'D PER ASSY	CODE IDENT NO	PART NUMBER	NOMENCLATURE OR DESCRIPTION	DRAWING OR DOCUMENT NO	ZONE	FIND NO
1		-120	BOLT		7	120
1		-119	WASHER		7	119
1		-118	BEARING		7	118
		-117	O RING		7	117
1		-116	RING		7	116
		-115	SPACER		7	115
		-114	RING		7	114
		-113	O RING		7	113
		-112	O RING		7	112
1		[illegible]	BOLT		7	
1		-110	WASHER		7	110
2		-109	STARTER ASSY		7	109
4		-108	WASHER		7	108
4		-107	NUT		7	107
1		-106	SEAL		7	106
1		-105	KEY		7	105
1		-104	CLUTCH ASSY		7	104
[illegible]		-103	BEARING		7	103
1		102	HOUSING		7	102
1		-101	GEARSHAFT		7	101
1		100	HOUSING		9	100
1		-99	HOUSING		8	99
1		98	SEAL		8	98
1		-97	IMPELLER		8	97
1		-96	SPACER		8	96
1		-95	FUEL CONTROL ASSY		8	95
1		94	SCREW		9	[illegible]
1		-93	WASHER		8	93
		-92	O RING		8	92
		91	SPACER		9	91
2		90	O RING		8	90
1		-89	GEARSHAFT		8	89
1		88	O RING		9	88
1		87	GEARSHAFT		8	87
		86	SPACER		8	86
1		85	RING		8	85
[illegible]		84	BEARING		8	84
2		83	KEY		8	83
		82	GEAR		9	82
		81	NUT		[illegible]	81
		719580-70	RING		[illegible]	80
		79	O RING		[illegible]	79
6		78	PIN		[illegible]	78
2		77	RING		[illegible]	77
		76	SEAL LAND		4	76
		75	SEAL		4	75
		74	RING		4	74
		73	BEARING		4	73
		72	RING		4	72
1		71	RING		4	71
1		70	SEAL LAND		4	70
1		69	SEAL		4	69
2		68	KEY		4	68
1		67	NUT		4	67
1		66	SPACER		4	66
1		65	RING		4	65
1		64	ROTOR		4	64
1		63	SPACER		4	63
2		62	BEARING		4	62
3		719580-42	BOLT		5	61

QTY REQ'D PER ASSY	CODE IDENT NO	PART NUMBER	NOMENCLATURE OR DESCRIPTION	DRAWING OR DOCUMENT NO	ZONE	FIND NO
1		719580-41	COVER		5	60
3		719580-40	NUT		5	59
3		719580-39	T CANE		5	58
1		-57	COMBUSTOR		5	57
1		-56	NOZZLE		5	56
2		55	SEAL		5	55
2		-54	RING		5	54
1		-53	"O" RING		6	53
1		-52	SPACER		6	52
1		-51	SEAL		6	51
1		-50	RING		6	50
1		49	"O" RING		6	49
2		48	RING		6	48
1		47	GEAR		6	47
1		719580-69	RING		6	46
2		719580-67	RING		6	45
2		719580-68	BEARING		6,7	44
1		719580-66	BEARINGS		7	43
		719580-73	RING		7	42
1		41	RING		7	41
1		719580-72	SEAL		7	40
1		39	HOUSING		7	39
1		38	RING		7	38
1		719580-71	GEAR		7	37
2		36	BEARING		7	36
1		719580-74	ADAPTOR		7	35
1		719580-59	PIN		7	34
1		719580-75	"V" BAND ASSY		7	33
1		719580-65	PIN		7	32
1		31	COVER		7	31
1		719580-64	COUNTERWEIGHT		7	30
1		719580-63	SCREW		7	29
		719580-62	NUT		7	28
1		719580-61	HOUSING		7	27
		719580-60	SPRING		7	26
2		719580-58	BEARING		7	25
		719580-78	SPRING		7	24
[illegible]		719580-77	RING		6,7	23
2		22	PIN		6,7	22
		21	"O" RING		[illegible]	21
		719580-57	PLUNGER		7	20
		9	GEAR		6	19
		8	GEAR		6	18
		17	SHAFT		6	17
		[illegible]	RING		6	16
		5	GEAR		6	15
		4	RING		6	14
		3	BEARING		6	13
		2	WIPER		6	12
			SEAL		[illegible]	
		10	HOUSING		[illegible]	10
		[illegible]	COVER		[illegible]	9
		8	DIFFUSER		[illegible]	8
		[illegible]	SUPPORT		[illegible]	7
		[illegible]	CASE		5	6
		5	SHAFT		5	5
						4
		3	TUBE			3
						2
		1	NOZZLE			1

TELEDYNE CAE

[illegible] FUEL STARTER ENGINE ASSEMBLY MODEL [illegible]

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Figure A-7. Model 206-A1 Engine Assembly (Bill of Materials).

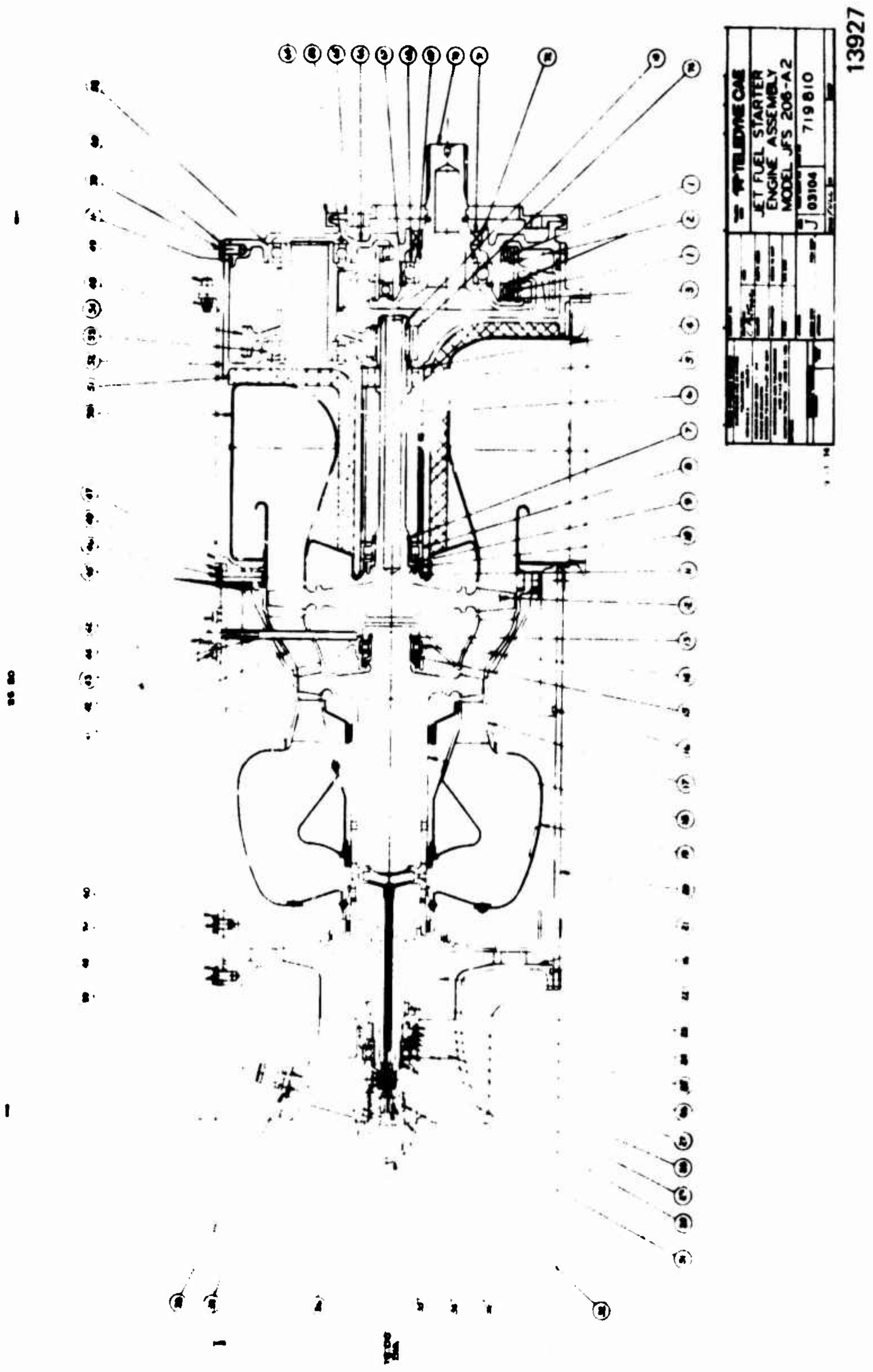

Figure A-8. Model 206-A2 Engine Assembly (Elevation).

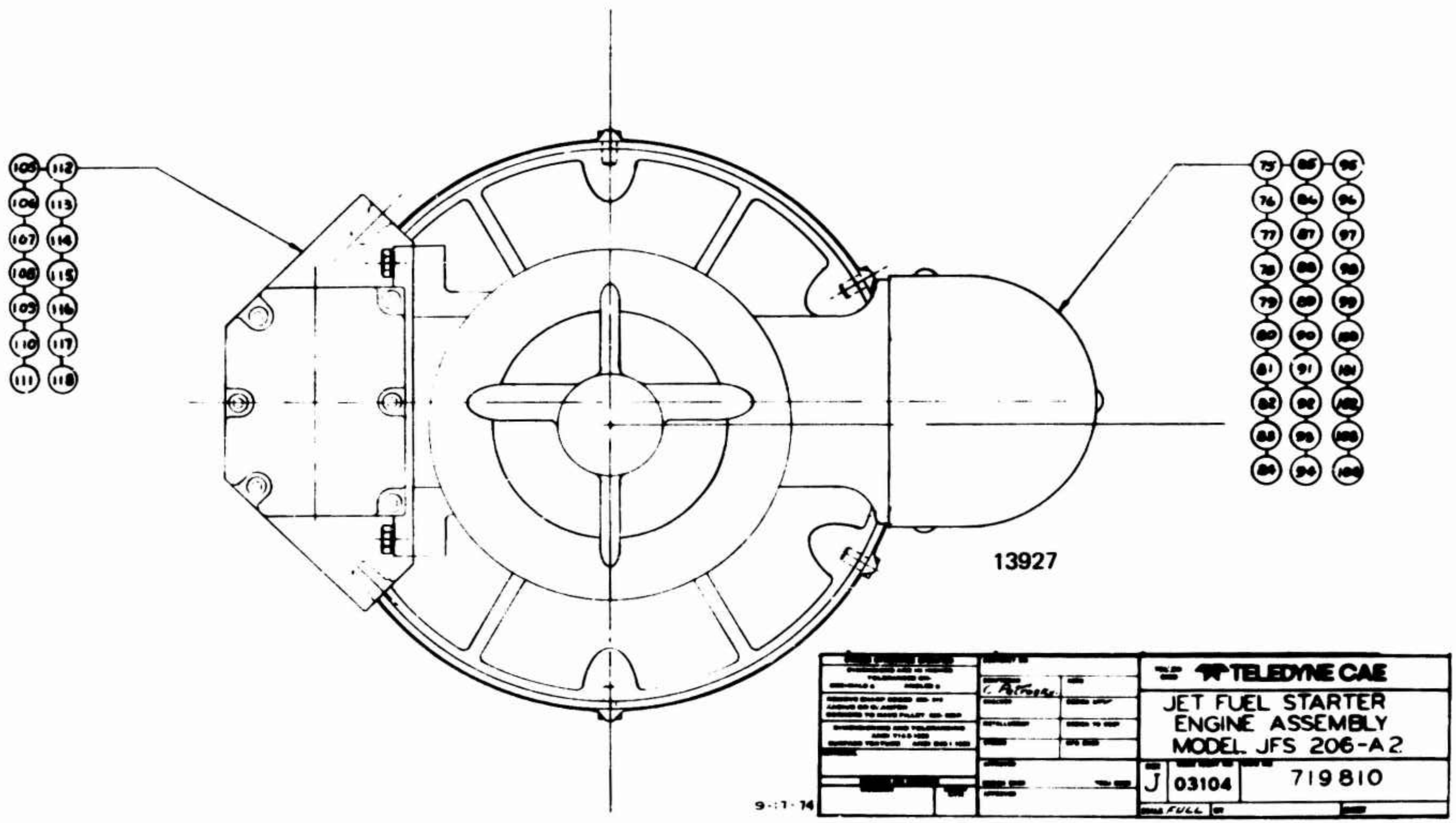

Figure A-9. Model 206-A2 Engine Assembly (End View).

PART NUMBER	NOMENCLATURE OR DESCRIPTION	DRAWING NO OR DOCUMENT NO	ZONE	FIND NO
8	WASHER		11	118
117	BOLT		11	117
[illegible]	"O" RING		11	116
5	SHAFT		11	115
4	O RING		11	114
3	SPACER		11	113
2	O RING		11	112
	WASHER			
[illegible]	SCREW			[illegible]
09	SPACER			109
08	IMPELLER		11	108
07	SEAL		11	[illegible]
06	HOUSING		11	106
05	FUEL CONTROL ASSY		11	105
104	O RING		9	104
03	WASHER		9	103
02	NUT		9	102
01	SCREEN		9	101
00	BAND		9	100
99	HOUSING		9	99
98	O RING		9	98
97	KEY		9	97
96	NUT		9	96
95	STARTER ASSY		9	95
94	GEAR		9	94
93	CLIP		9	93
92	SHIELD		9	92
91	RING		9	91
90	SHAFT		9	90
89	RING		9	89
88	BEARING		9	88
87	SPACER		9	87
86	GEAR		9	86
85	SEAL		9	85
84	RING		9	84
83	BEARING		9	83
82	CLUTCH ASSY		9	82
81	PIN		9	81
80	RING		9	80
79	GEAR		9	79
78	RING		9	78
77	BEARING		9	77
76	HOUSING		9	76
75	GEAR		9	75
74	GEAR		[illegible]	74
73	RING		[illegible]	73
72	RING		[illegible]	72
9580 72	SEAL		[illegible]	[illegible]
9580 [illegible]	GEAR		[illegible]	70
9580 73	RING		5	69
9580 66	BEARING		[illegible]	68
9580 70	RING		[illegible]	67
9580 69	COVER		[illegible]	66
9580 74	ADAPTOR		[illegible]	65
9580 75	BAND		5	64
9580 65	PIN		5	63
9580 64	COUNTERWEIGHT		[illegible]	62
9580 61	SCREW		[illegible]	[illegible]

PART NUMBER	NOMENCLATURE OR DESCRIPTION	DRAWING NO OR DOCUMENT NO	ZONE	FIND NO
9580 62	NUT		5	60
9580 61	HOUSING		5	59
9580 60	SPRING		5	58
9580 59	PIN		5	57
9580 58	SPRING		5	56
9580 57	PLUNGER		5	55
9580 47	GEAR		5	54
9580 56	BEARING		5	53
52	CASE		6	52
51	INSULATION		6	51
50	DUCT		6	50
49	BOLT		6	49
48	NUT		6	48
47	RING		6	47
46	PIN		6	46
45	RING		6	45
44	ADAPTOR		6	44
43	TUBE		6	43
42	SCREW		6	42
41	NOZZLE		7	41
9580 77	RING		5,6,7	40
39	PIN		5,7	39
38	FITTING		8	38
37	"O" RING		8	37
36	SHAFT		8	36
35	FAIRING		8	35
34	SEAL		8	34
33	O RING		8	33
32	O RING		8	32
31	"O" RING		8	31
30	RING		8	30
29	BEARING		8	29
28	WIPER		8	28
27	CARRIER		8	27
26	SEAL		7	26
25	O RING		7	25
24	RING		7	24
23	RING		7	23
22	COMPRESSOR		7	22
21	HOUSING		7	21
20	CASE		7	20
9	COMBUSTOR			19
8	SHAFT			18
7	NOZZLE			17
9580 27	O RING		5,7	16
15	SEAL		6	15
4	BEARING		6	14
3	RING		6	13
2	ROTOR		6	12
	RING		6	
10	SEAL LAND		6	
9	SEAL		6	9
8	BEARING		6	8
7	RING		6	7
6	SPACER		6	6
5	BEARING		6	5
4	RING		5	4
9580 69	RING		5	3
9580 67	RING		5	2
9580 68	BEARING			

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TELEDYNE CAE

JET FUEL STARTER ENGINE ASSEMBLY MODEL JFS 206-A2

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Figure A-10. Model 206-A2 Engine Assembly (Bill of Materials).

APPENDIX B

DETAILED COST DRAWINGS

Detailed cost drawings were prepared for complex parts where the starter assembly drawing did not provide adequate data for estimating labor and material cost. These drawings are shown in Figures B-1 through B-9.

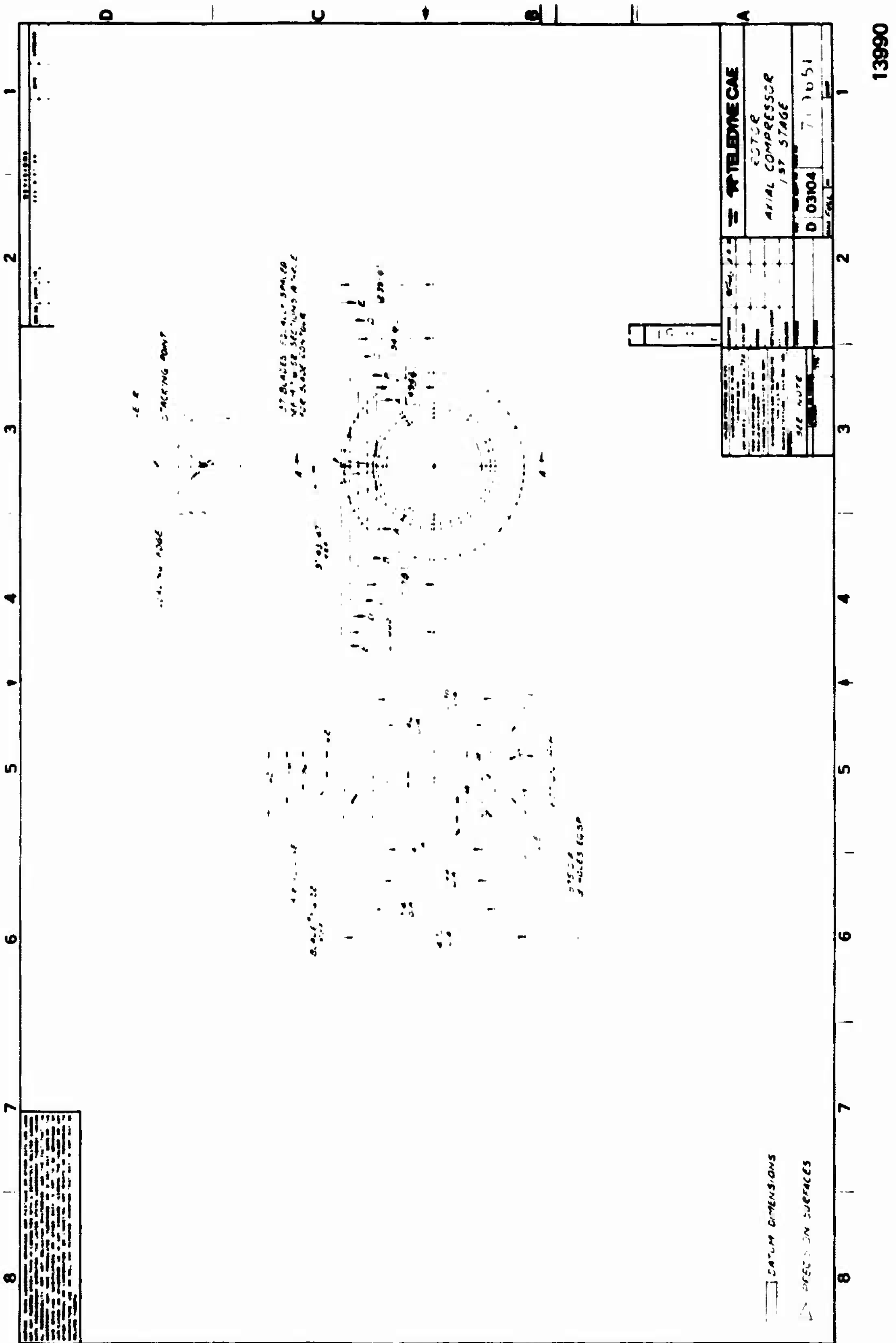


Figure B-1.

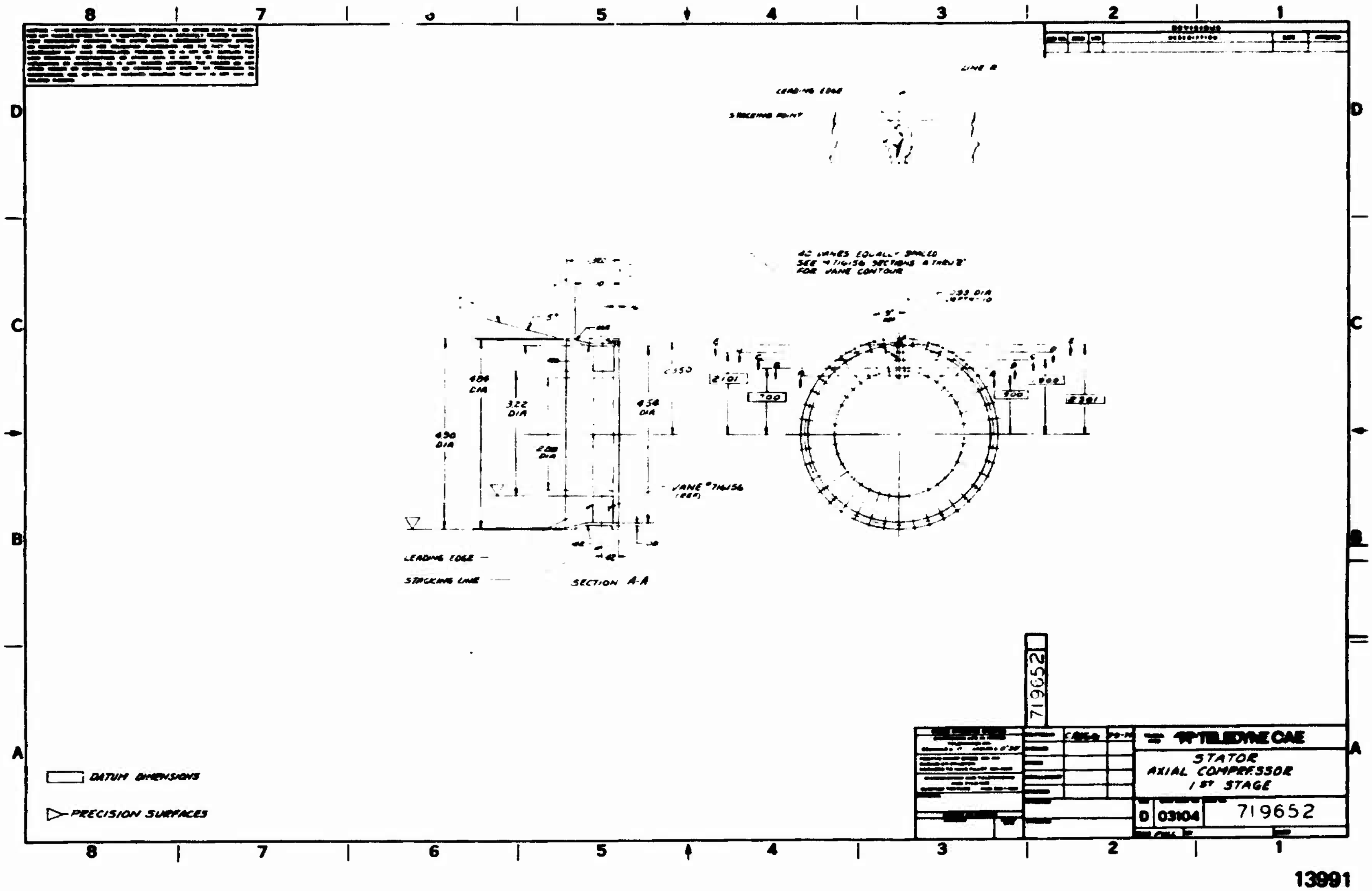
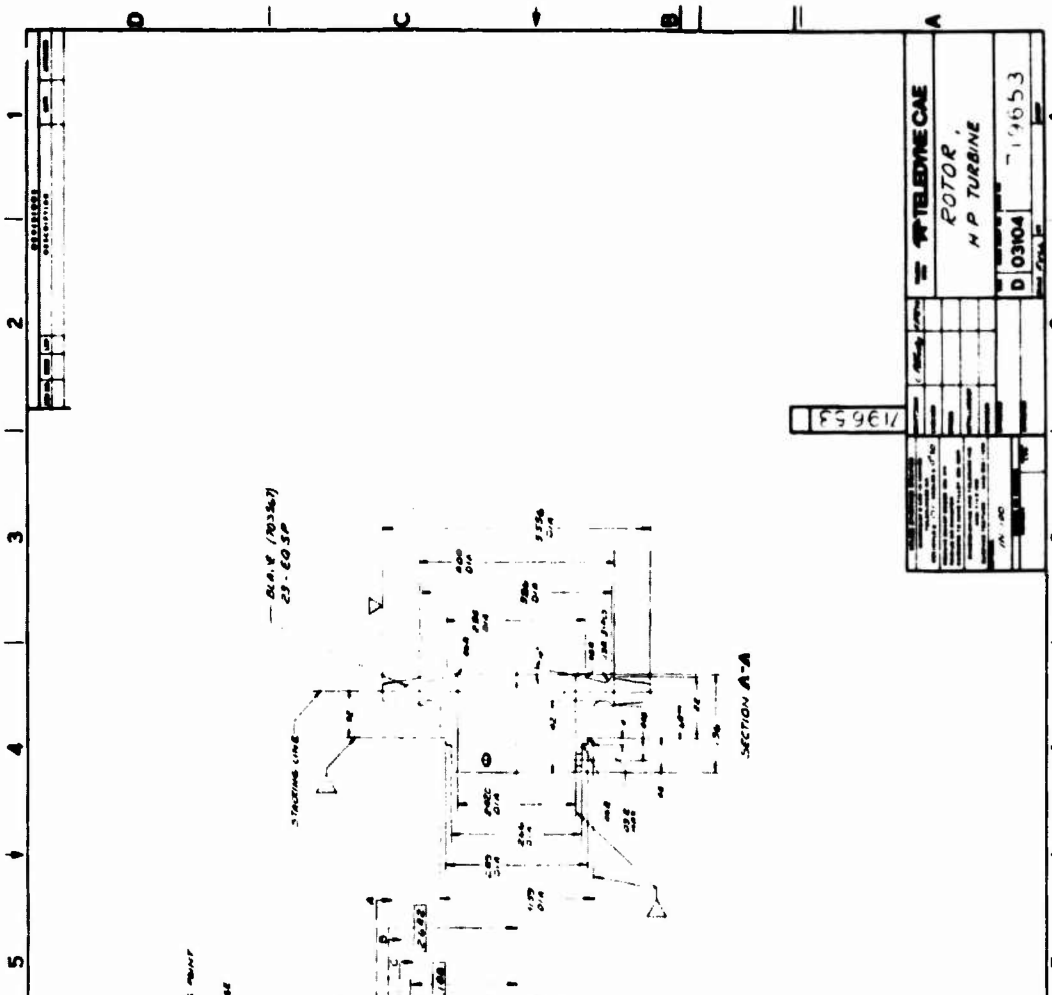

LINE R
LEADING EDGE
STACKING POINT
42 VANES EQUALLY SPACED
SEE #716156 SECTIONS A THRU E
FOR VANE CONTOUR
SECTION A-A
LEADING EDGE
STACKING LINE
VANE #716156
DATUM DIMENSIONS
PRECISION SURFACES
TELEDYNE CAE
STATOR
AXIAL COMPRESSOR
1ST STAGE
D 03104 719652
719652
13991

Figure B-2.



13992

Figure B-3.

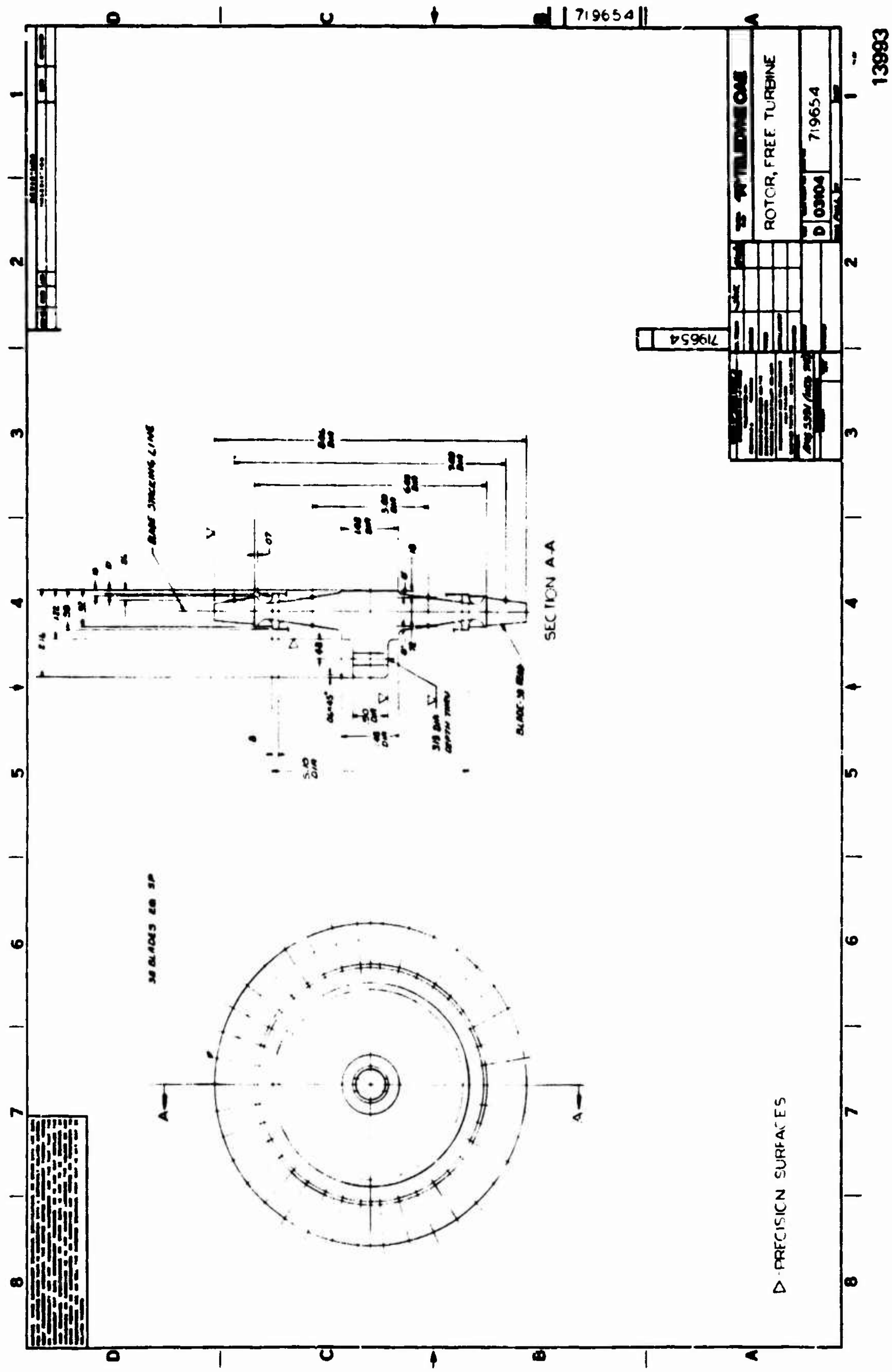

ROTOR, FREE TURBINE
719654
SECTION A-A
PRECISION SURFACES
13993

Figure B-4.

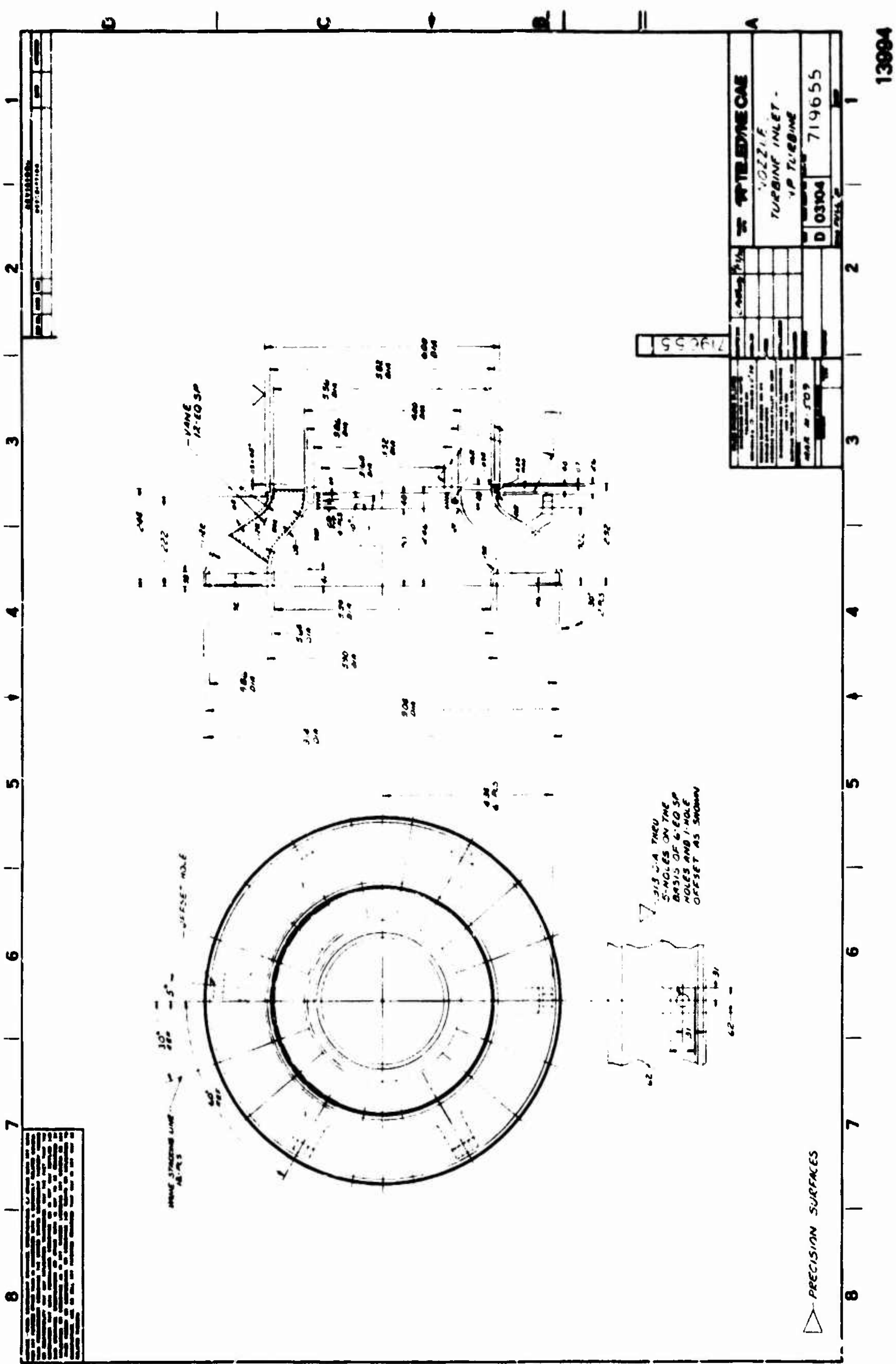


Figure B-5.

13995

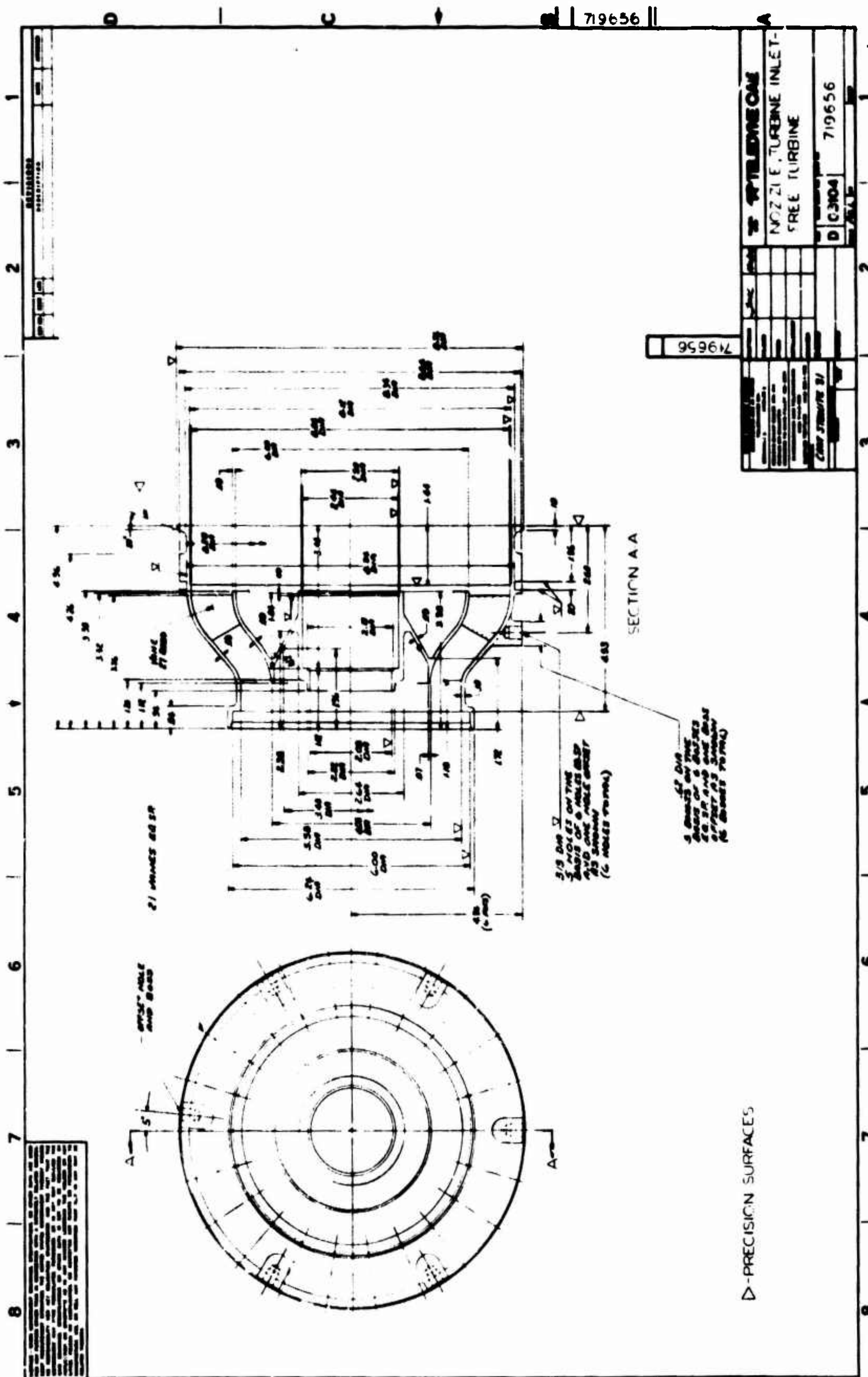


Figure B-6.

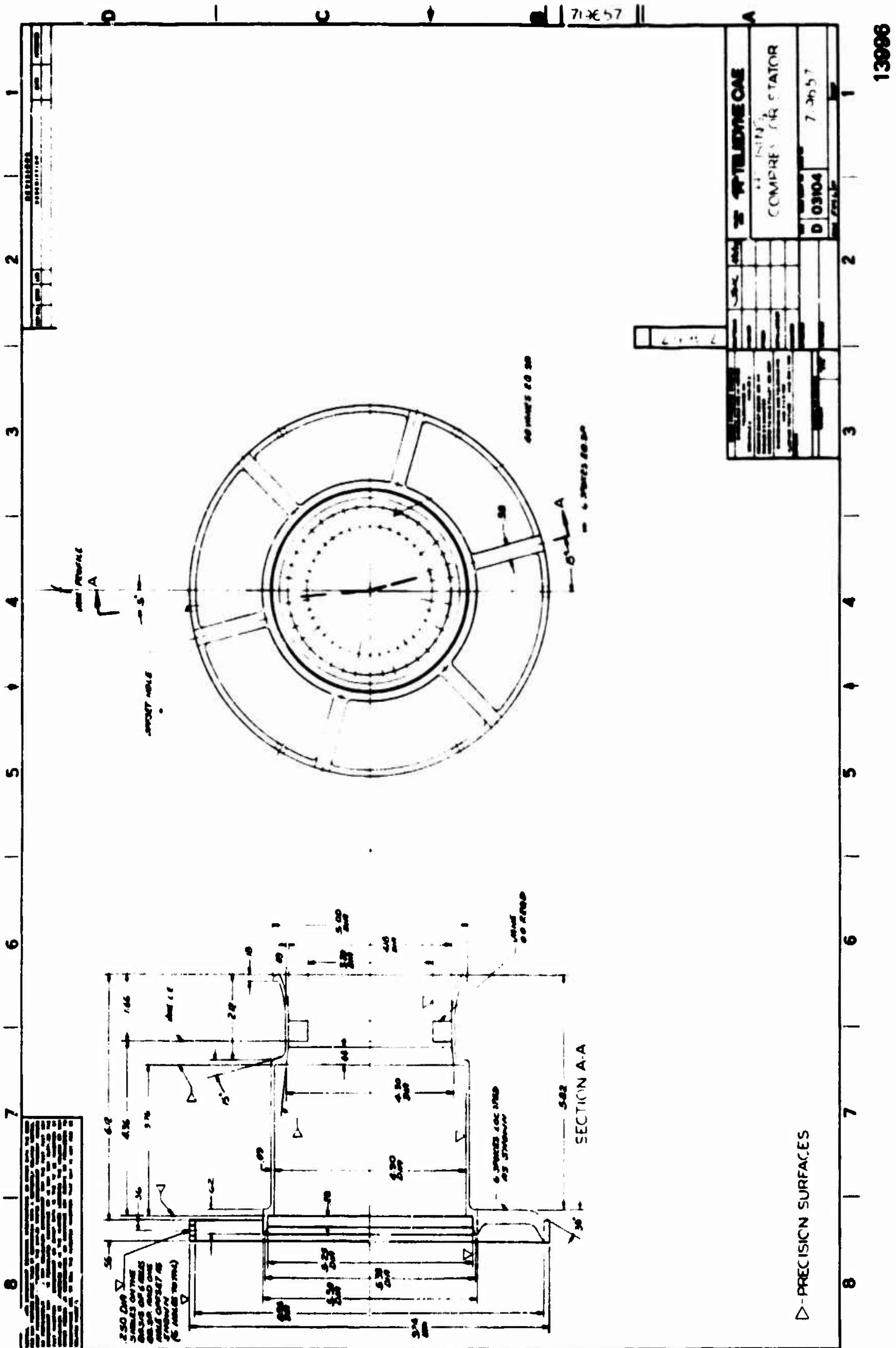

TELEDYNE CAE
COMPRESSOR STATOR
D 03104
SECTION A-A
▷ - PRECISION SURFACES
13996

Figure B-7.

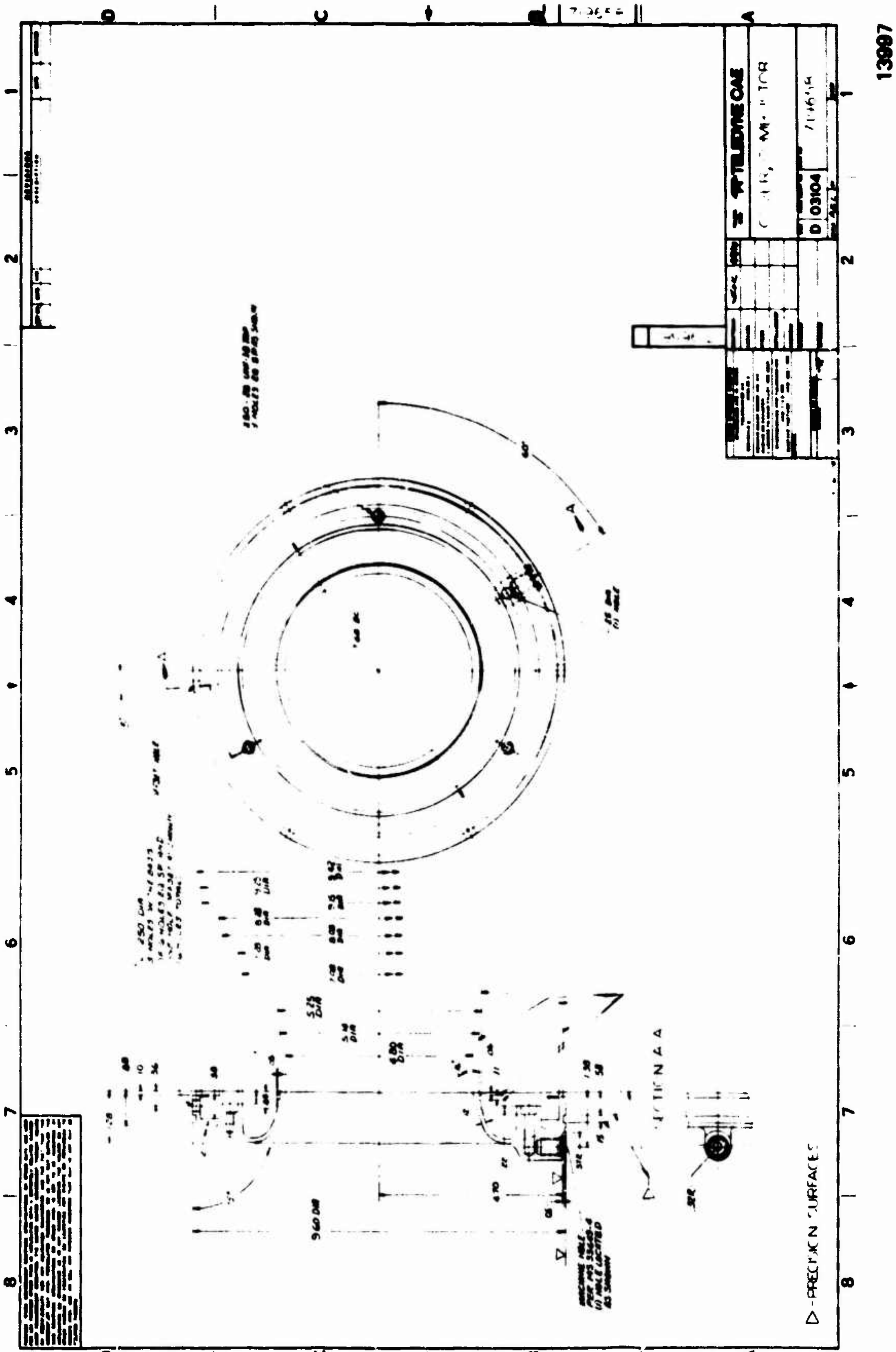


Figure B-8.

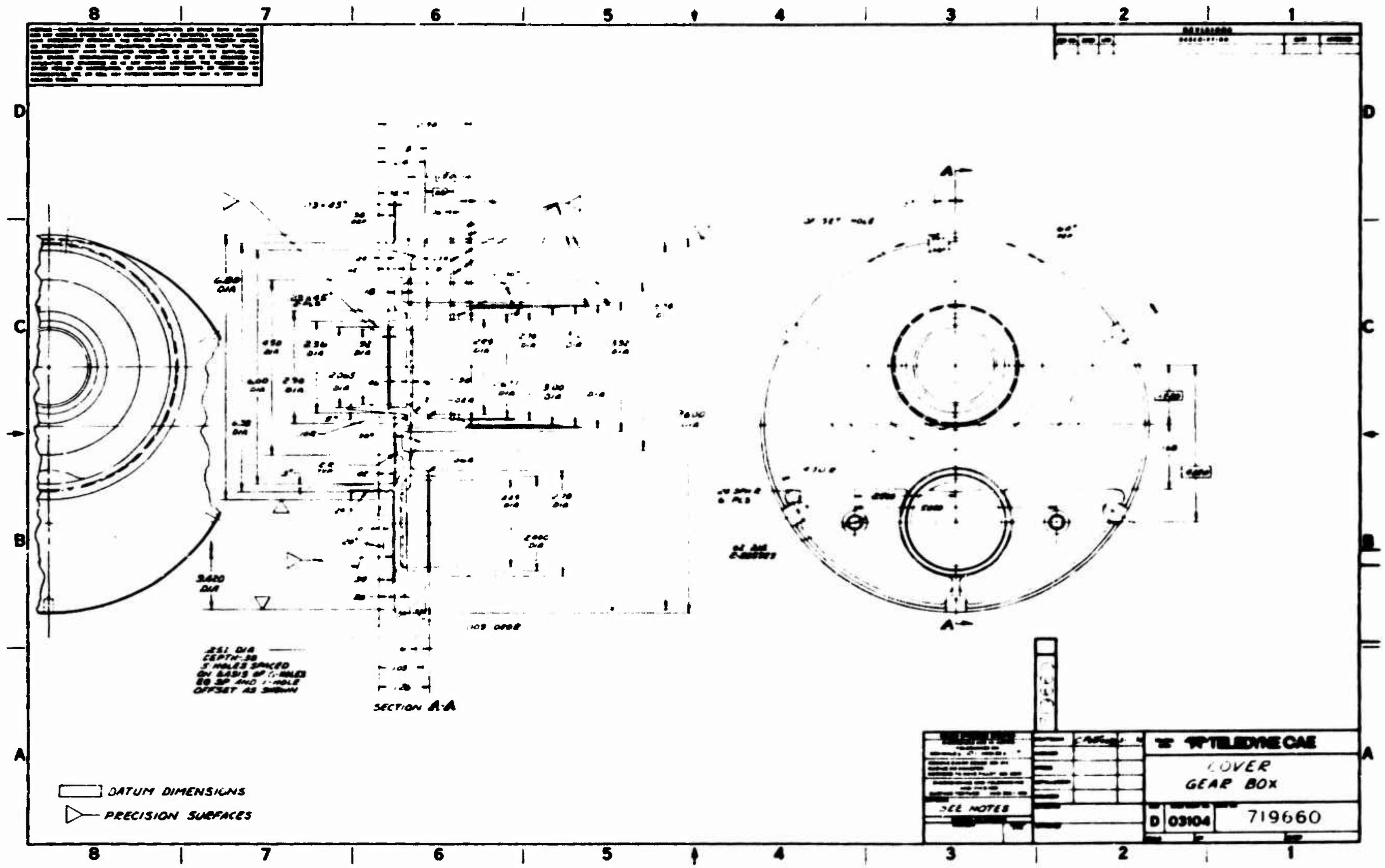


Figure B-9.

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APPENDIX C

DESIGN POINT DATA

The engine design point computer printout data for the JFS206 jet fuel starter is shown in Figure C-1. The starter cycle, component efficiencies and pressure losses for the JFS206 A-1 and JFS206 A-2 were considered to be equal, and the computer printout data for this cycle is shown in Figure C-2.

DESIGN POINT CALCULATIONS-REGENERATED TURBOSHAFT ENGINE
SINGLE SPOOL,FREE TURBINE PROGRAM 30.038

DATE9 5 74 NAME SINGH S091568
JET FUEL STARTER
469-4STAGE AXIAL WITH INLET RECV
FREE TURBINE

INPUT

	ALT	M	TA	PA	P2/P1	
100	0.0	0.0	0.0	0.0	0.99000 00	
	ETA COMB	LHV	EM	ETA N	HPE	F/A CONT
200	0.95000 00	0.1840D 05	0.96000 00	0.10000 01	0.0	0.0
	BO	BC	BHC	BHH	BL	WA
300	0.0	0.0	0.0	0.0	0.0	0.2228D 01
	DP/PHC	DP/PC	DP/PIT	DP/PD	DP/PHH	P10/PA
400	0.0	0.5000D-01	0.1500D-01	0.5000D-01	0.0	0.10100 01
	P3/P2	ETA C	ETA T	T5	ETA PT	EHE
500	0.2857D 01	0.8000D 00	0.82500 00	0.22600 04	0.80000 00	0.0
	NPT	N	(ETA-CP)I	(ETA-TP)I	(ETA-PTP)	
600	0.10000 03	0.43500 05	0.0	0.0	0.0	

OUTPUT 30.038

TA	0.5187D 03	PA	0.1470D 02	N/RTH2	0.4350D 05	N/RTH5C	0.2115D 05
T2	0.5187D 03	P2	0.1455D 02	WRT/02	0.2251D 01	WH/D605	0.6161D 03
T3	0.7444D 03	P3	0.4157D 02	NPT/T7C	0.5070D 02	DHT/T5C	0.1286D 02
T4	0.7444D 03	P4	0.4157D 02	WN/D6C7	0.2251D 01	DHT/N2	0.2875D 07
T5	0.2260D 04	P5	0.3949D 02	DHPT/T7	0.1285D 02	DH/N2PT	0.4999D-02
T6	0.2074D 04	P6	0.2523D 02	P3/P2	0.2857D 01	ETA C	0.8000D 00
T7	0.2074D 04	P7	0.2485D 02	P5/P6	0.1565D 01	ETA T	0.82500 00
T8	0.1901D 04	P8	0.1562D 02	P7/P8	0.1590D 01	ETA PT	0.80000 00
		P9	0.1484D 02	P10/PA	0.1010D 01	ETA N	0.1000D 01
T10	0.1901D 04	P10	0.14840 02	DP/PHC	0.0	ETA COM	0.9500D 00
WA	0.2228D 01	P11	0.1484D 02	DP/PC	0.5000D-01		
W3	0.2228D 01	TAU	0.7943D 04	DP/PIT	0.1500D-01		
W5	0.2283D 01			DP/PD	0.5000D-01		
W7	0.2283D 01			DP/PHH	0.0		
W10	0.2283D 01			DP/PN	0.0		
WRT/P8	0.63700 01	BO	0.0	EHE	0.0	F.A	0.2452D-01
FN	0.1807D 02	FG	0.1807D 02	AJ	0.61700 02	WF	0.1967D 03
SHP	0.1512D 03	BSFC	0.1301D 01	ESHP	0.15850 03	ESFC	0.1241D 01
ETA-CP	0.82680 00	ETA-TP	0.8172D 00	ETA-PTP	0.7910D 00		

Figure C-1. Model 206 Jet Fuel Starter Design Point Data.

DESIGN POINT CALCULATIONS-REGENERATED TURBOSHAFT ENGINE
SINGLE SPOOL,FREE TURBINE PROGRAM 30.038

DATE9 9 74   NAME SINGH   S091619
JFS MODEL 206-A-1
CENTRIFUGAL COMPRESSOR NC=74%
WA=1.95 PR=3.9

INPUT

	ALT	M	TA	PA	P2/P1	
100	0.0	0.0	0.0	0.0	0.99000 00	
	ETA COMB	LHV	EM	ETA N	HPE	F/A CONT
200	0.9500D 00	0.1840D 05	0.9600D 00	0.1000D 01	0.0	0.0
	B0	BC	BHC	BHH	BL	WA
300	0.0	0.0	0.0	0.0	0.0	0.1950D 01
	DP/PHC	DP/PC	DP/PIT	DP/PO	DP/PHH	P10/PA
400	0.0	0.5000D-01	0.1500D-01	0.5000D-01	0.0	0.1010D 01
	P3/P2	ETA C	ETA T	T5	ETA PT	EHE
500	0.3900D 01	0.7400D 00	0.8250D 00	0.2260D 04	0.8000D 00	0.0
	NPT	N	(ETA-CP)I	(ETA-TP)I	(ETA-PTP)I	
600	0.1000D 03	0.5500D 05	0.0	0.0	0.0	

OUTPUT 30.038

TA	0.5187D 03	PA	0.1470D 02	N/RTH2	0.5500D 05	N/RTH5C	0.2673D 05
T2	0.5187D 03	P2	0.1455D 02	WRT/02	0.1970D 01	WN/D605	0.4986D 03
T3	0.8485D 03	P3	0.5674D 02	NPT/T7C	0.5178D 02	DHT/T5C	0.1886D 02
T4	0.8485D 03	P4	0.5674D 02	WN/D607	0.1808D 01	DHT/N2	0.2639D-07
T5	0.2260D 04	P5	0.5390D 02	DHPT/T7	0.1500D 02	DH/N2PT	0.5593D-02
T6	0.1986D 04	P6	0.2744D 02	P3/P2	0.3900D 01	ETA C	0.7400D 00
T7	0.1986D 04	P7	0.2703D 02	P5/P6	0.1965D 01	ETA T	0.8250D 00
T8	0.1789D 04	P8	0.1562D 02	P7/P8	0.1730D 01	ETA PT	0.8000D 00
		P9	0.1484D 02	P10/PA	0.1010D 01	ETA N	0.1000D 01
T10	0.1789D 04	P10	0.1484D 02	DP/PHC	0.0	ETA COM	0.9500D 00
WA	0.1950D 01	P11	0.1484D 02	DP/PC	0.5000D-01		
W3	0.1950D 01	TAU	0.7778D 04	DP/PIT	0.1500D-01		
W5	0.1995D 01			DP/PO	0.5000D-01		
W7	0.1995D 01			DP/PHH	0.0		
W10	0.1995D 01			DP/PN	0.0		
WRT/P8	0.5401D 01	B0	0.0	EHE	0.0	F/A	0.2293D-01
FN	0.1532D 02	FG	0.1532D 02	AJ	0.5231D 02	WF	0.1610D 03
SHP	0.1481D 03	BSFC	0.1087D 01	ESHP	0.1542D 03	EBSFC	0.1044D 01
ETA-CP	0.7835D 00	ETA-TP	0.8131D 00	ETA-PTP	0.7892D 00		

Figure C-2. Model 206-A1 & 206-A2 Alternate Designs Design Point Data.

APPENDIX D

DERIVATIVE ENGINES

APPLICATIONS

Derivative engines, utilizing components from an existing design will decrease cost by increasing the production base. The basic jet fuel starter design is readily adapted to thrust engine applications, both as a turbojet and a turbofan. The thrust class, 130 to 265 pounds, is suitable for Remotely Piloted Vehicles (RPV) propulsion.

TURBOJET DERIVATIVE

The turbojet derivative (Figure D-1) produces 130 pounds of thrust and weights only 40 pounds. The basic engine is 20 inches long, 10 inches in diameter and features a self-contained control system. The addition of a commercial electric starter and generator will increase the weight by 12 pounds for a total of 52 pounds.

The design uses the basic jet fuel starter gas generator, consisting of the four-stage axial compressor, the combustor, and single-stage gas generator turbine. A new combined front frame and air inlet housing are provided along with an integral rear frame, exhaust duct and jet nozzle.

The fuel control is driven through a tower shaft by a face gear originating from gas generator which in turn drives a low speed (2,000 rpm) ring gear concentric with the engine. This ring gear provides the drive for a 12-volt electric starter and generator. The starter and generator selected are currently in high production for outboard engines and are readily available low cost units. The ring gear construction is similar to that used in the outboard engine industry except instead of a flywheel mount, it is carried by three grease-packed roller bearings. The front thrust bearing and gear drive system are pot lubed and the rear bearing is lubricated by waste fuel supplied through the center of the gas generator shaft. The engine performance is summarized in Table D-1.

TURBOFAN DERIVATIVE

The turbofan derivative (Figure D-2) uses both the gas generator and low pressure turbine section from the jet fuel starter. A front frame carries the gas generator thrust bearing, fan stator, shrouds, and the fan rotor and provides the support for the fan shaft thrust bearing. An exhaust duct and jet nozzle provides the primary (hot stream) exhaust. A full length fan duct directs the fan flow to the rear and provides a separate fan nozzle. The accessory drive system is similiar to that discussed for turbojet derivative. The outboard engine starter and generator are utilized along with the low speed ring gear. The thrust bearings and face gear drives are pot lubed and

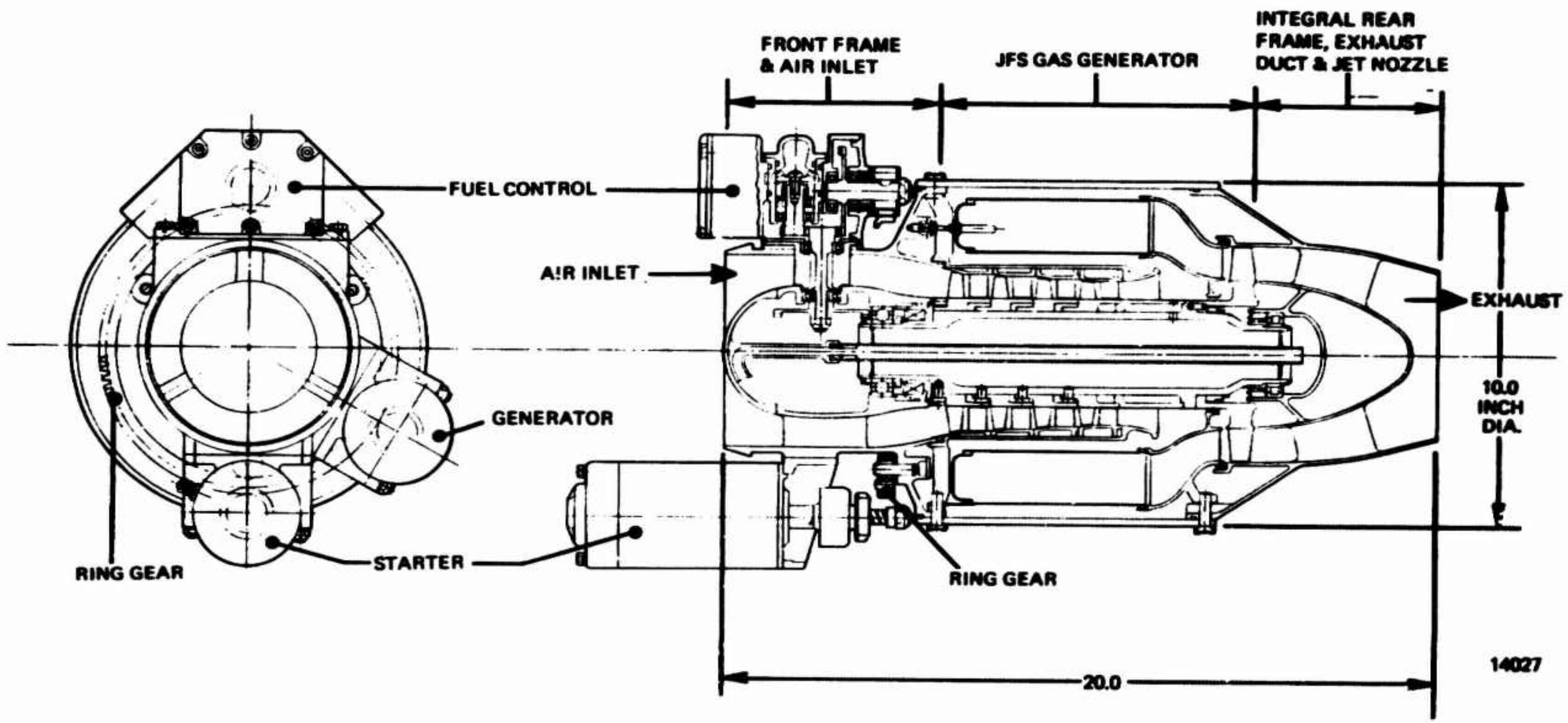

Figure D-1. Turbojet Derivative of Jet Fuel Starter.

TABLE D-1

TURBOJET PERFORMANCE SUMMARY

PARAMETER	SEA LEVEL STATIC	SEA LEVEL MACH 0.7	20,000 FT. MACH 0.7
THRUST (lbs)	130	120	72
SFC (lbs/hr/lb)	1.50	1.54	1.70
AIRFLOW (lbs/sec)	2.23	2.95	1.54

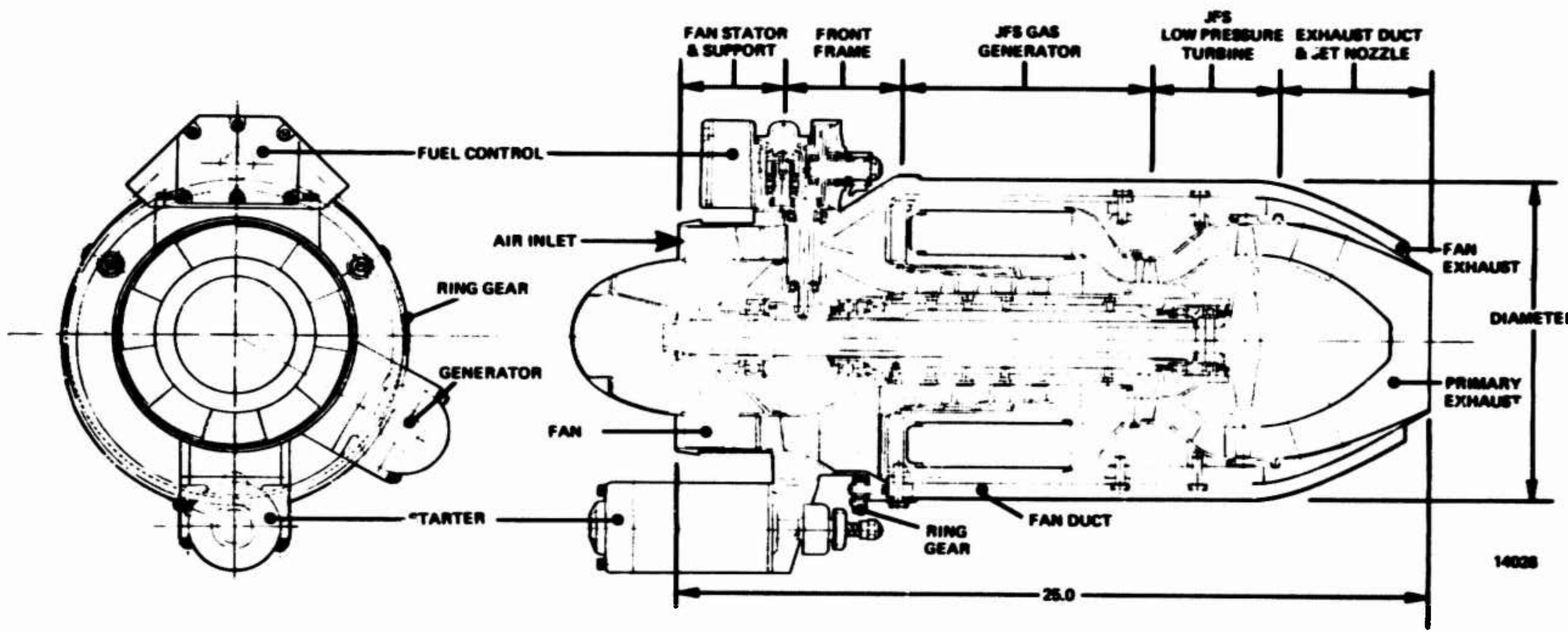

Figure D-2. Turbofan Derivative of Jet Fuel Starter.

the rear bearing lubed by waste fuel, utilizing a separate line within the fan duct to transmit the fuel to the rear bearing cavity. Compressor discharge air is bled into the bearing cavity to stabilize the temperature and to prevent hot gases from the turbine from entering the bearing cavity. The basic turbofan engine is 11.0 inches in diameter, 25.0 inches long and weighs 90 pounds. The addition of the starter and generator increases the weight by 12 pounds for a total of 102 pounds. The engine performance is summarized in Table D-2.

TABLE D-2

TURBOFAN PERFORMANCE SUMMARY

PARAMETER	SEA LEVEL STATIC	SEA LEVEL MACH 0.7	20,000 FT. MACH 0.7
THRUST (lbs)	265	204	122
SFC (lbs/hr/lb)	0.97	1.50	1.42
AIRFLOW (lbs/sec)	7.14	9.6	4.95

*U.S.Government Printing Office: 1975 — 657-020/521